AD-A141 991 NETWORK REPAIR LEVEL ANALYSIS MODEL USER'S GUIDE(U) AIR FORCE LOGISTICS COMMAND WRIGHT-PATTERSON AFB OH L BRISKIN JAN 84 1/2

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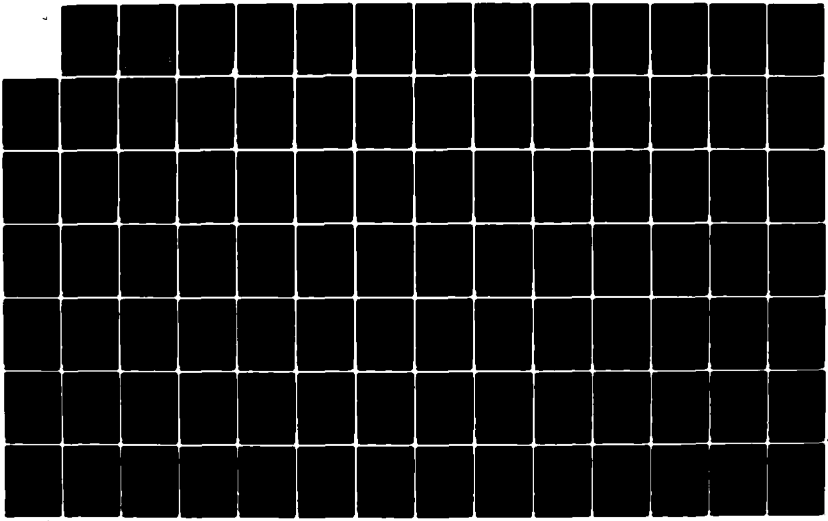

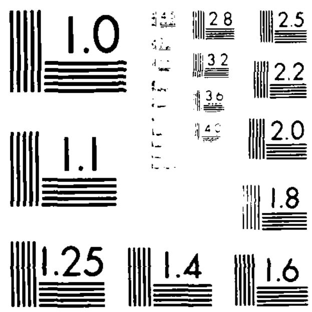

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AD-A141 991

NETWORK REPAIR LEVEL ANALYSIS MODEL

USER'S GUIDE

JANUARY 1984

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PREFACE

This user's guide describes a model for determining repair level decisions by considering life cycle maintenance related costs. The model formulates the repair level decision problem as a network analysis problem. This approach was chosen because it explicitly considers the indenture level relationships between items (Line Replaceable Units (LRUs) and (Shop Replaceable Units (SRUs)), and considers support equipment as a resource shared by a group of items. Although the decision problem is formulated as a cost network it is not necessary for the user to construct the network or manually solve it. This is done by the computer program written for the model.

This edition is identical to the February 1983 version except that (a) several appendices issued after that date have been incorporated into the body of the work, (b) procedures for handling multiple identical SRUs in an LRU and one type of SRU in several LRUs are given, and (c) some technical explanations have been expanded. The explanation of the operation of the network, the glossary of variables, and the NRLA cost equations have been removed from the main body but retained as appendices. The main body of the text now consists of material required to understand why Network Repair Level Analysis is done, data preparation, and interpretation of output.

Earlier editions of this guide should be discarded.

1. General Description

1.1 Repair level analysis (RLA) is the general process of determining whether components of weapons systems or other systems should be repaired or scrapped and, if repaired, where repaired. The regulation Repair Level Analysis Program (AFSCR/AFLCR 800-28) gives policy. The pamphlet Repair Level Analysis Procedures (AFLCP/AFSCP 800-4, 25 Nov 83) gives technical procedures. The pamphlet describes several ways of doing repair level analysis including network repair level analysis (NRLA).

NRLA is the preferred means of performing RLA. (a) It solves the RLA problem for line replaceable units (LRUs) and shop replaceable units (SRUs). (b) It solves the problem by failure mode, recognizing that an LRU may fail in any of several different ways. It treats the individual failure modes as part of the overall problem. (c) Most important, it treats the problem of shared support equipment (SE) successfully. When different items share use of SE, item repair level analysis (IRLA) and other solution procedures require proration of SE costs to the LRU or SRU to achieve a solution. It can be shown that any proration procedure is inherently incorrect. The NRLA computer program structures the problem as a network, solves the network and achieves a systemwide optimal solution to the problem with no proration.

The repair level decisions involve choosing among the alternatives: depot-level repair, discard, and intermediate level repair. For many components, all reparable failure modes are assigned the same repair alternative; however, some components may, for example, have intermediate repair assigned for some failure modes and depot repair assigned for other failure modes. Included among the factors influencing each repair-level decision are the life cycle costs associated with each repair level, mobility and deployment requirements for the end-item, available maintenance personnel and skill levels at base and depot, and the availability of support equipment and repair facilities at base and depot.

The NRLA model described here deals only with economic factors affecting the repair level decisions. Thus, the repair level recommendations made by the model must be used in conjunction with the non-economic factors when making final repair level decisions.

In the model, the economic analysis of repair level decisions is based on specific life cycle costs associated with each repair level option. However, the NRLA model is not a comprehensive life cycle cost (LCC) model because it does not attempt to include all life cycle cost elements. It only includes those costs which directly impact the repair level decisions.

As its name implies, the NRLA model formulates the repair-level decision problem in terms of a network. This approach is used because it specifically considers line replaceable unit (LRU) to shop replaceable unit (SRU) indenture-level relationships and it treats each unique support equipment (SE) as a repair resource which may be shared by a group of LRUs and/or SRUs. In essence, the model uses life cycle-costs with LRU/SRU/SE interdependency relationships to construct a network representation of the repair level decision problem. Details of network construction and solution are given in the appendices.

1.2 Updating NRLA. When a NRLA user is to begin a new program, it is his responsibility to confirm with the program office or AFALC/XRS that he has a current version of the NRLA computer program. When NRLA updates become available during the course of a program, these changes should be implemented with consent of the program office and AFALC/XRS. Any programming changes made as a result of this paragraph must be at no charge to the government unless normal contract change procedures have been followed.

1.3 Basic Approach. The NRLA model is an analytical technique to be used as an aid in making repair-level decisions. This technique is fundamentally different from the previous Air Force repair-level analysis methodology in a number of significant ways. (1) The model recognizes LRU and SRU indenture-level relationships and uses the information to preclude inconsistent decisions; for example, discarding a failed LRU and doing base repair for one or more SRUs within it. (2) It determines repair-level recommendations simultaneously for all the failure modes of a group of LRUs and for the SRUs associated with the LRUs, as opposed to considering each failure mode and SRU independently. (3) The support equipment required to accomplish LRU and/or SRU repair is considered to be a resource whose cost must be economically justified by the group of LRUs and/or SRUs which require it. This cost is jointly shared by the group of items requiring the resource; however, the cost is not prorated to the individual items in the group. (4) Finally, as a consequence of these fundamental differences the model is able to make repair-level recommendations such that the total cost for the group of LRUs and SRUs is minimized. Thus, the model determines the economically optimum set of repair level decisions for the entire group of items.

The model determines repair level recommendations based solely on economic considerations. The costs associated with each repair level option are those which are specifically incurred as a result of choosing the option. Thus, the life cycle costs for spares and support equipment are included because the total expenditure is a function of the repair-level decisions. Conversely, costs associated with repair-in-place maintenance and LRU removal from the end-item are not included in the model because they are incurred regardless of the off-equipment repair-level decision.

Cost values used by the model for determining repair-level decisions are based on data factors relevant to the: (1) end-item utilization, (2) maintenance system costs, (3) supply system costs, (4) support equipment costs, and (5) LRU and SRU costs.

Throughout the NRLA pamphlet the following definition applies: Life cycle cost means life cycle costs with respect to the NRLA model. Therefore, the term life-cycle cost, as used throughout this user's guide, means the total cost to the government over the life of the system which can be affected by the repair-level decision. This may vary greatly from cost values derived from other kinds of LCC models.

1.4 Model Assumptions. The model makes a number of assumptions which should be understood by the user. Appropriate modifications should be made to the model if these assumptions are not valid for a particular application.

1. The logistics system is composed of some number of operational locations (bases) and some number of centralized repair facilities (depots) supporting the bases. The user specifies the number of bases and the level of end-item utilization at a base (assumed to be equal for all bases). The number of depots utilized by the bases is not specified because it is irrelevant. It is assumed that if the bases send a particular LRU or SRU to a depot for repair, then all bases send their reparables of that item to the same depot for repair. Thus, the system behaves as if there were only one depot.

2. Base-level maintenance system data (available work time per man, labor rate, and turnover rate) are assumed to be equal for all bases and all types of repair tasks. It is also assumed that the corresponding data factors are constant for the depots and the various repair tasks accomplished at depot level.

3. Supply system data factors (see Chapter 2) are assumed to be constant for all LRUs and SRUs being analyzed. Thus, the order and shipping time from depot to each CONUS base is a constant for every item. Similarly, the order and shipping time from depot to each overseas base is a constant.

4. Only one set of technical data is purchased from the contractor. Further, duplication and distribution costs for additional sets of data are minor and are ignored.

5. Scheduled maintenance actions are not specifically considered by the model. If they exist they may be included by designating an additional failure mode for the affected items and appropriately modifying the LRU failure rate.

6. The model explicitly evaluates each LRU failure mode for a repair level decision; however, a simplifying assumption is made for SRUs. It is assumed that the different failure modes of an SRU are sufficiently similar (in terms of support equipment, repair time, and repair skills) so that explicitly evaluating the principle SRU failure mode is adequate.

7. Depot stock of SRUs is computed to satisfy base-level demands for SRUs, that is, to resupply the bases when they send SRUs to depot for repair. Thus, the SRU stock level supports base level SRU remove and replace maintenance actions but not depot level remove and replace actions.

1.5 Treatment of Support Equipment. The major difference between the NRLA model and some other repair level analysis techniques is the treatment of support equipment and its cost. The rationale for the NRLA approach can best be explained by illustrating a problem inherent in Item Repair Level Analysis (IRLA).

Suppose that five different items (LRUs and/or SRUs) are being analyzed for repair-level decisions and that all five items require the same piece of new support equipment which costs $10,000. Further, suppose that each of the five items would require precisely the same amount of support equipment time per month and that one unit of the SE would be more than adequate for all repairs.

When considering the base level repair option for these items, some repair-level analysis techniques prorate the $10,000 SE cost. In this case, $2,000 is applied to each item. This leads to a problem if some, but not all of the items, are selected for base level repair.

For example, the analysis might recommend base repair for three items and depot repair for two of the items. This result would imply that two of the items could not economically justify their $2,000 share of the SE cost, the other three could. Unfortunately, these decisions only account for 60% of the total SE cost. Therefore, it would be necessary to reallocate the SE cost to the three items and once again determine the repair level recommendations. Unfortunately, it is again possible that at least one of the three items would not get a base-level repair recommendation. Consequently, the total SE cost might have to be reallocated again and the process repeated.

Successively eliminating items from consideration for base repair could lead to a depot-level decision for each item when, in fact, it is economically justifiable to repair them at base level. That is, there could be some percentage allocation of the $10,000 such that each of the five items could economically justify its share. As an example, suppose the above five items could economically justify SE expenditures of $3500, $3500, $2000, $1000, and $1000, respectively. The iterative SE cost allocation procedure described above would ultimately lead to a depot repair decision for each of the five items even though they collectively could economically justify the expenditure of $11,000 for SE. Determining the best way to allocate SE costs is often extremely difficult, particularly when many items and/or many support equipment resources are involved.

The NRLA model has a distinct advantage over proration methods because it avoids the proration problem by not attempting to allocate SE costs to individual items. In the network formulation the total cost for each SE is structurally tied to each LRU and SRU which requires the SE. This structural tie is constructed in a way that permits the network solution algorithm to select only the SE resources which are economically justified by the using items and which minimize overall costs.

It should be noted that IRLA was satisfactory when SE costs were relatively low compared to total RLA costs. As SE costs have risen, the proration problem has become acute, leading to the development of NRLA.

2. NRLA Program Operation

2.1 Introduction

The NRLA Program has been set up to make it easy for the user to understand the input and the output. Acronyms have deliberately been avoided in the output for this reason.

There are eight types of data records used for input: (1) Weapons System Data and Options, (2) Maintenance System Data, (3) Supply System Data (Figure 1), (4) Support Equipment Data (Figure 2), (5) LRU Description (Figure 3), (6) LRU Failure Modes (Figure 4), (7) SRU Data Record (Figure 5), and (8) SE Resource Numbers (Figure 6).

Identification of input records is as follows. Input data records are numbered two ways, (1) by data record type, and (2) by the entries in columns 1 and 2. The former are for rapid reference by the user. The latter are for use by the program. Table 1 shows the relationship.

Table 1

DATA RECORD RELATIONSHIPS

DATA RECORD NAME	DATA RECORD TYPE	COLUMN*	
		1	2
Weapons System	1	-	-
Maintenance System	2	-	-
Supply System	3	-	-
Support Equipment	4	1	-
LRU	5	3	1
LRU Fail Mode	6	4	1
SRU	7	5	1
		3	2
LRU/SRU/SE	8	4	2
CROSS REFERENCE		5	2

*The "-" means that input section gives the required entires.

There are also eight types of output: (1) General Information, (2) Support Equipment Input Values, (3) LRU/SRU/SE Relationships, (4) Computed Support Equipment Costs, (5) Support Equipment Requirements, (6) Repair Level Decisions, (7) Repair Level Decision Details, and (8) Sensitivity Analysis. The output will be discussed in Chapter 3.

The Data Input Forms, Figures 1-6 are suitable for reproduction. Figure 7 contains a listing of the data used to generate the sample problem.

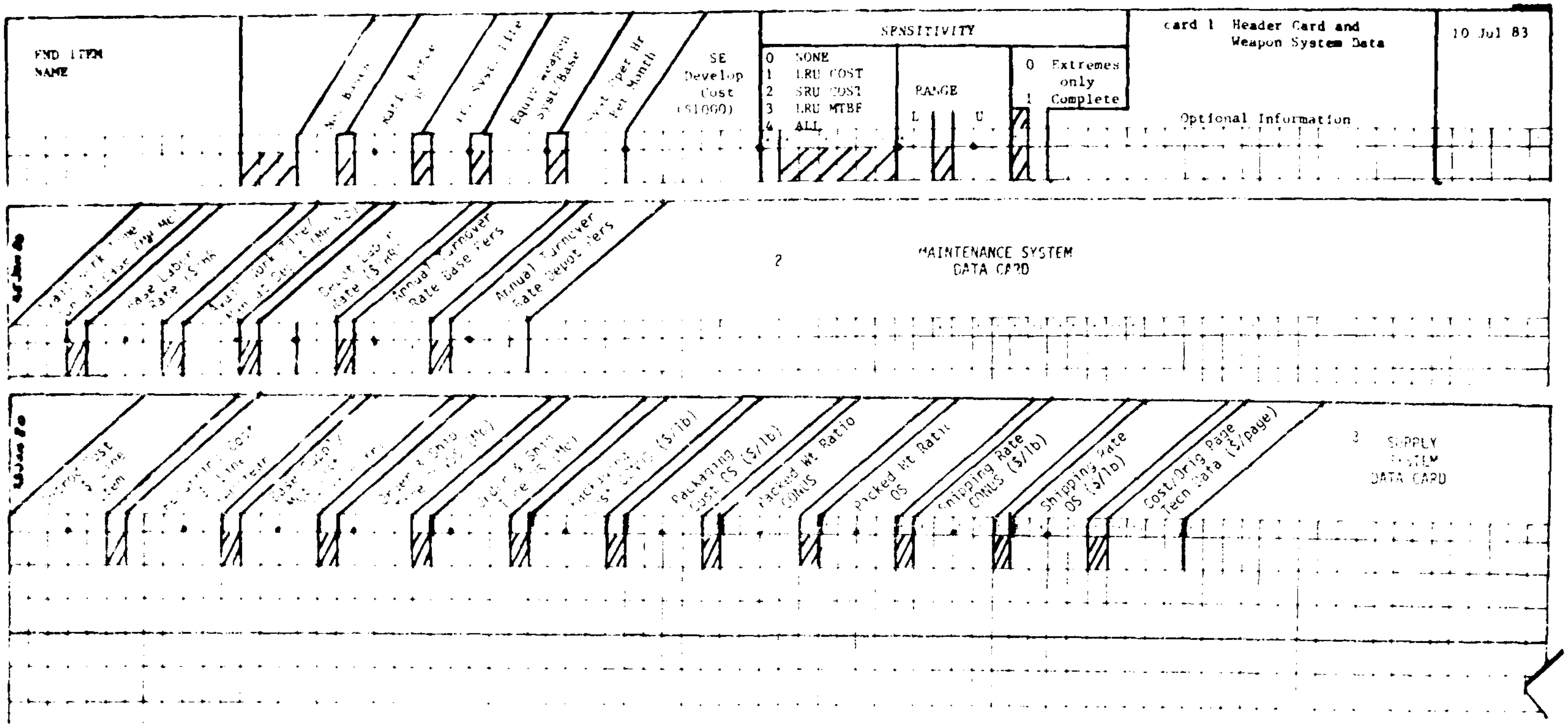
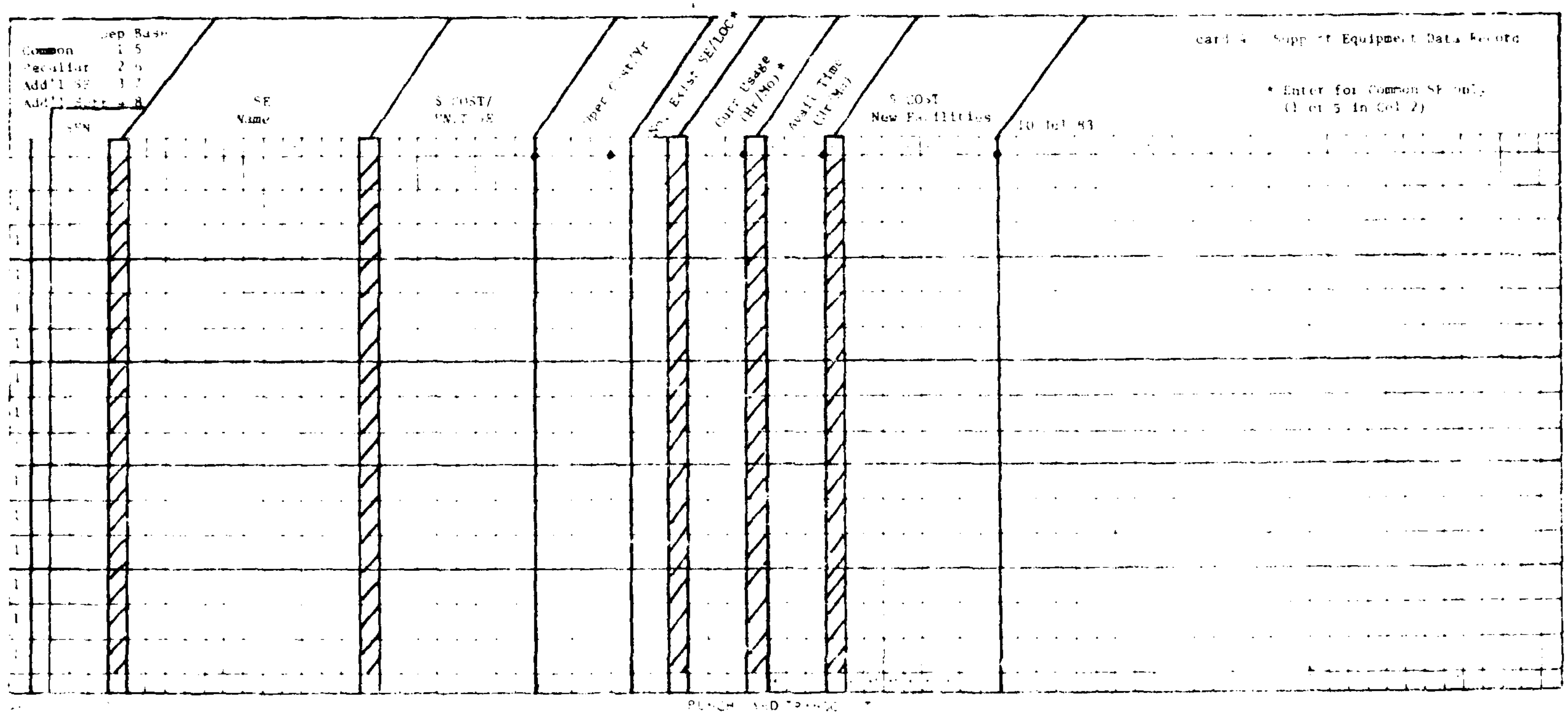


Figure 1. General Information Data Cards



NOTE: Column 2 (only) must be entered in ascending order.

Figure 2. Support Equipment Data Card

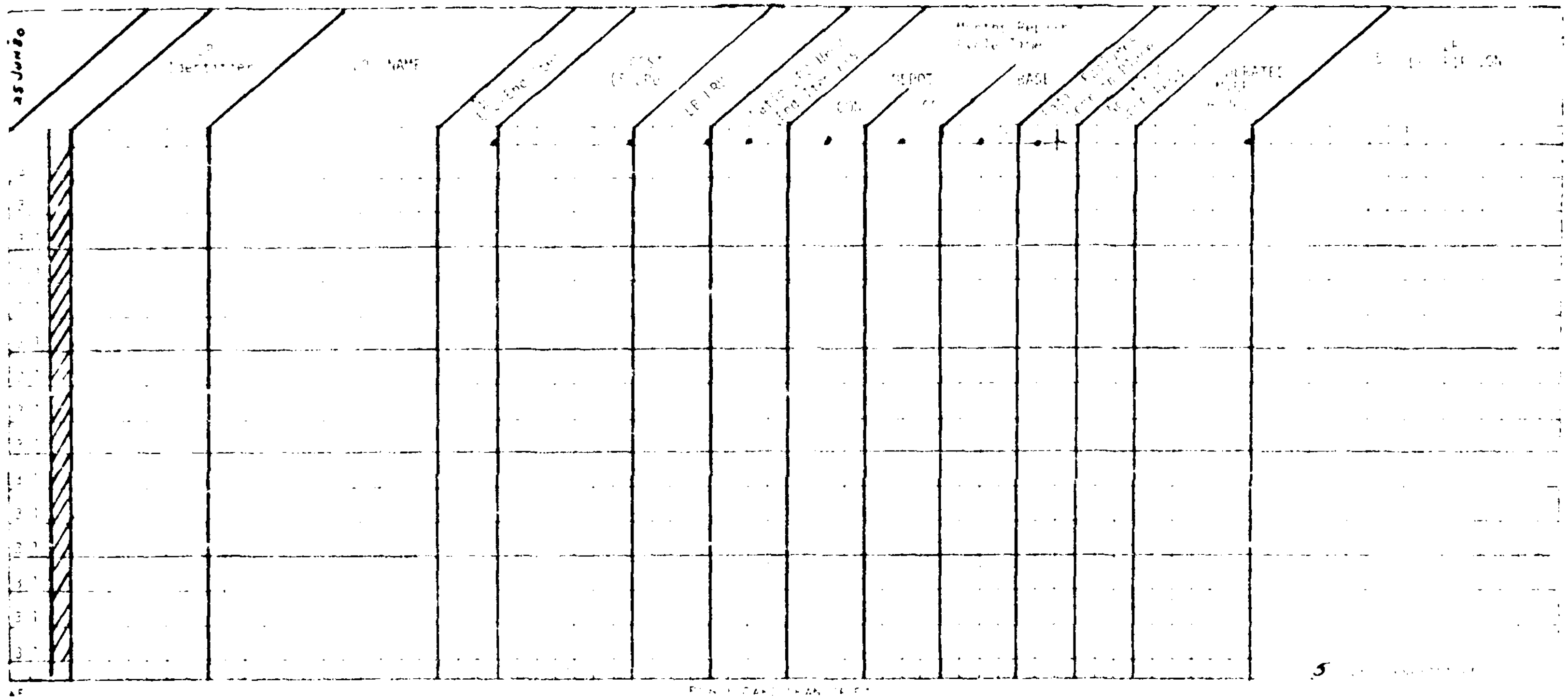
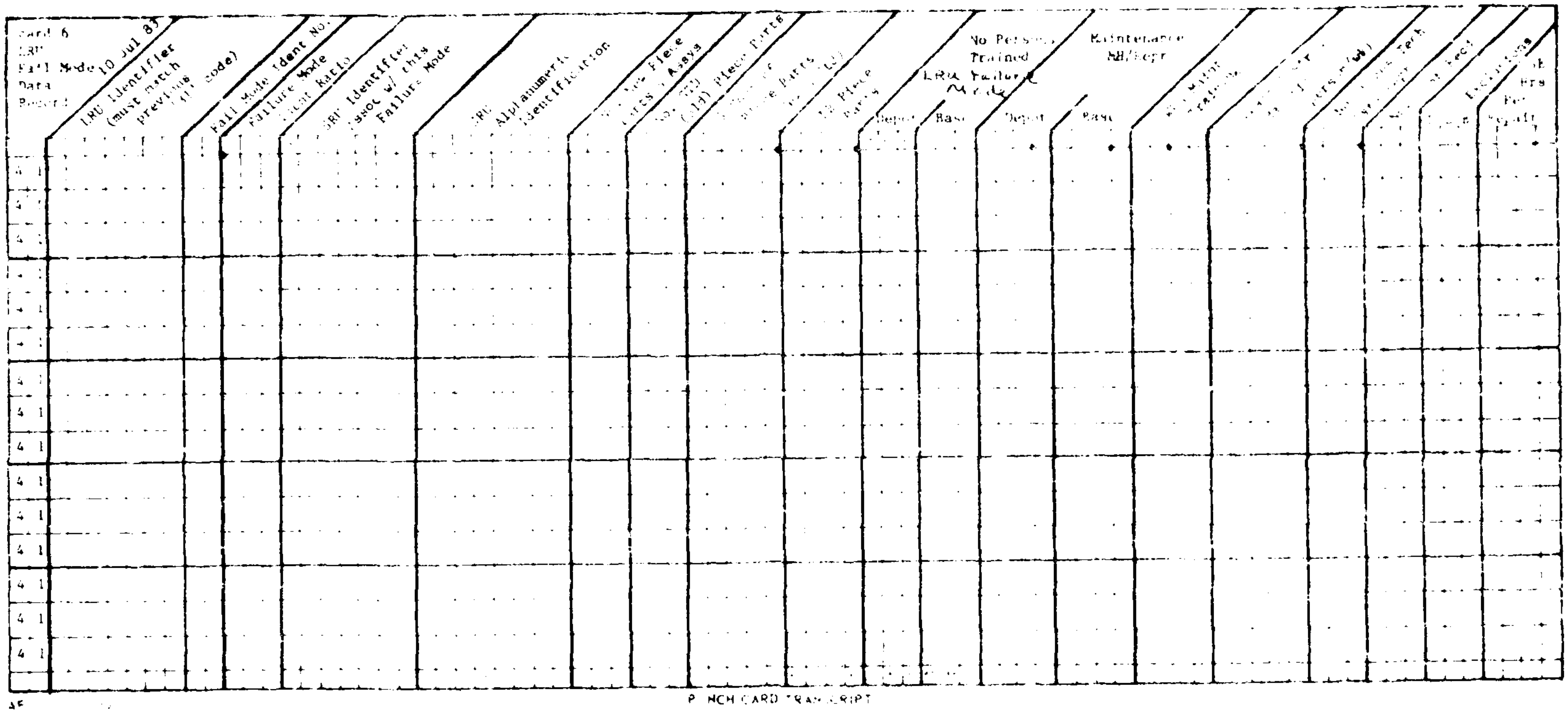


Figure 3. LRU Data Card



NOTE: All failure modes of a particular LRU must be grouped together.

Figure 4. LRU Failure Mode Data Card

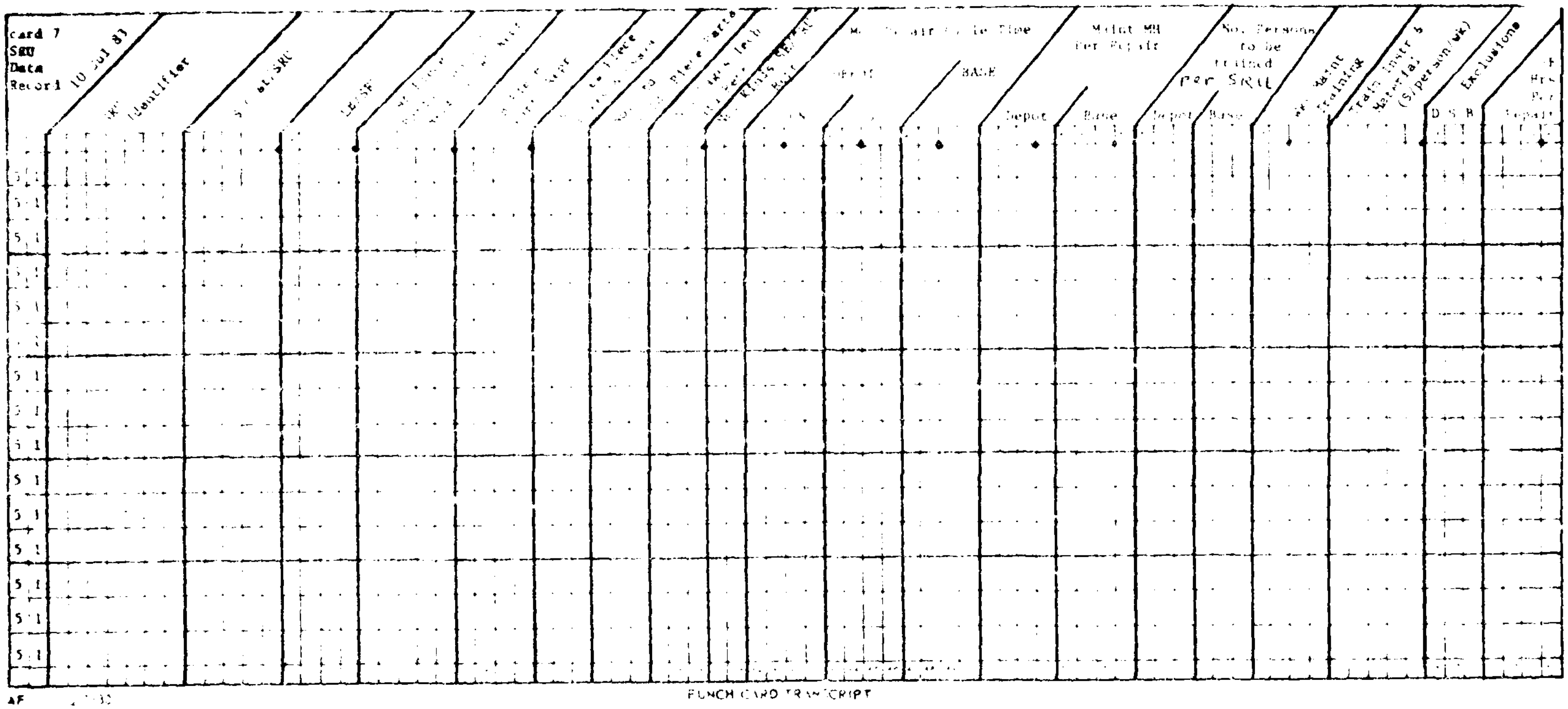


Figure 5. SRU Data Card

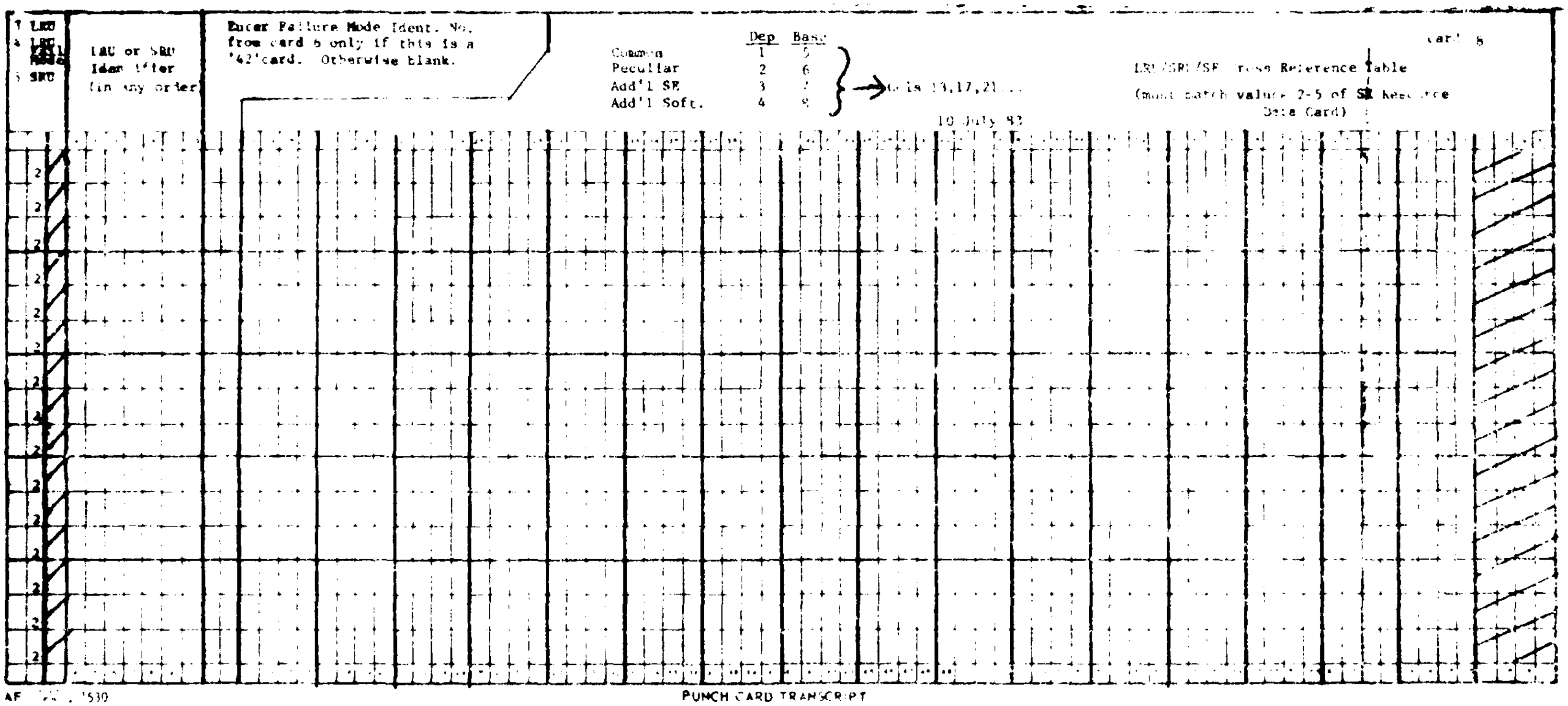


Figure 6. SE Resource Numbers Data Card

```
MOD.THRT.EMT   47 020 10   1 120   10004      50 200 1THIS AREA FOR RUN IDENT.
132 1642 136 3485 0.33 0.15
10420 10420 20.0 0.27 0.53 0.43 0.54 1.28 1.44 .389 .573 190.
11001 MULTIMETER         90. 1.80 1 2.5 200         0
12002 OSCILLOSCOPE     2375. 47.5 1 1.8 200         0
12003 SIGNAL.GEN.      4750. 95.0 1 1.2 200         0
12004 PULSE.GEN.       1350. 27.0 1 0.5 200         0
12005 POWER.SUPPLY      600. 12.0 1 2.5 200         0
12006 UNIV.BRIDGE      1375. 27.5 1 0.1 200         0
15001 MULTIMETER.*       90. 1.80 1 2.5 200         0
16002 OSCILLOSCOP*     2375. 47.5 1 1.8 200         0
16003 SIGNAL.GEN.*     4750. 95.0 1 1.2 200         0
16004 PULSE.GEN..*     1350. 27.0 1 0.5 200         0
16005 POWER.SUPP.*      600. 12.0 1 2.5 200         0
16006 UNIV.BRIDGE*     1375. 27.5 1 0.1 200         0
99
31 LRU02  ISOL REACTOR 4.   1280. 5.0 1.0 1.5 1.5 .33 .1  6 25000
31 LRU03  DESPIKER BD  4.   1394. 1.5 1.0 1.5 1.5 .33 .1  8  3000
31 LRU04  VAR PW ENERG 1.   5166. 1.5 1.0 1.5 1.5 .33 .1  6  3500
31 LRU05  SCR ASSY     1.   4552. 1.0 1.0 1.5 1.5 .33 .1  2  5000
31 LRU06  FAULT BD ASY 1.   1770. 1.0 1.0 1.5 1.5 .33 .1  8300000
31 LRU07  ENGY REG BD  1.   2306. 1.0 1.0 1.5 1.5 .33 .1  8  3500
31 LRU08  TRG AMP BD   1.   1524. 1.0 1.0 1.5 1.5 .33 .1 10  3500
31 LRU09  SWTCH SCR AY 1.  17670. 5.0 1.0 1.5 1.5 .33 .1  8  2500
31 LRU10  STOR CAP MAD 4.   2338. 0.3 1.0 1.5 1.5 .33 .1  4 15000
31 LRU14  PFN/SWT XFMR 1.  19810. 1.0 1.0 1.5 1.5 .33 .1  2  5000
31 LRU15  PULSE TRANSF 4.   5142. 25. 1.0 1.5 1.5 .33 .1  4  3500
31 LRU16  FIL PGM CARD 1.   2682. 1.0 1.0 1.5 1.5 .33 .1  8  2500
31 LRU17  MOTOR ASSY   2.   9656. 25. 1.0 1.5 1.5 .33 .1  2  7500
31 LRU18  ASSY MTR LD  1.   1250. 10. 1.0 1.5 1.5 .33 .1  2  5000
31 LRU19  RESISTOR ASY 4.   1170. 2.0 1.0 1.5 1.5 .33 .1  2 50000
31 LRU20  POWER SUPPLY 1.  11156. 45. 1.0 1.5 1.5 .33 .1  2 10000
31 LRU21  PWR SUP 15VD 1.    528. 3.4 1.0 1.5 1.5 .33 .1  2 15000
31 LRU22  INTLOCK CTRL 1.   2682. 1.0 1.0 1.5 1.5 .33 .1  8 10000
31 LRU23  PWR SUP 5VDC 1.  11156. 12. 1.0 1.5 1.5 .33 .1  2 15000
31 LRU24  PWR SUP 28VD 1.   1810. 35. 1.0 1.5 1.5 .33 .1  2 15000
31 LRU25  HI V PWR SUP 1.  15600. 40. 1.0 1.5 1.5 .33 .1  2  3500
31 LRU26  OVRTRVL SWTC 1.   3556. 0.5 1.0 1.5 1.5 .33 .1  0 10000
31 LRU27  T BITR REACT 1.   4000. 1.0 1.0 1.5 1.5 .33 .1  0 15000
99
```

Figure 7a. Data Listing of Sample Problem

```
41LRU02   11.0                 2  0 192. 1.0  6  2 .36 .36 .06 200.  3  0100 .36
41LRU03   11.0                 1  0 209. .01  6  2 .35 .35 .06 200.  4  0000 .35
41LRU04   11.0                 1  0 775. .01  6  2 .55 .55 .06 200.  3  0  1 .55
41LRU05   1.67SRU53  CCA.CHRG  1  0    0. .01  6  2 .41 .41 .06 200.  3  0     .41
41LRU05   2.33                 1  0 683. .05  6  2 .80 .80 .06 200.  2  0     .80
41LRU06   11.0                 1  0 266. .01  6  2 .65 .65 .06 200.  6  0     .65
41LRU07   11.0                 1  0 346. .01  6  2 .65 .65 .06 200.  5  0     .65
41LRU08   11.0                 1  0 229. .01  6  2 .65 .65 .06 200.  6  0 11  .65
41LRU09   1.17SRU54  DLAY.RCT  1  0    0. .10  6  2 .40 .40 .06 200.  1  0     .40
41LRU09   2.17SRU57  CS.TRANS  1  0    0. .01  6  2 .50 .50 .06 200.  1  0     .50
41LRU09   3.33SRU60  TTA.S.SC  1  0    0. .50  6  2 .55 .55 .06 200.  1  0     .55
41LRU09   4.33                 2  02651. .10  6  2 .53 .53 .06 200.  2  0     .53
41LRU10   11.0                 1  0 351. .01  6  2 .23 .23 .06 200.  5  0     .23
41LRU14   1.71SRU55  SWT.TRNS  1  0    0. .20  6  2 .80 .80 .06 200.  3  0     .80
41LRU14   2.25SRU56  PLS.FNET  1  0    0. .01  6  2 .55 .55 .06 200.  3  0     .55
41LRU14   3.04                 1  02972. .30  6  2 .40 .40 .06 200.  4  0     .40
41LRU15   1.14SRU51  PLST.TOR  1  0    0. 1.0  6  2 .46 .46 .06 200.  2  0     .46
41LRU15   2.35SRU52  FILT.TOR  1  0    0. 1.0  6  2 .46 .46 .06 200.  3  0     .46
41LRU15   3.51                 3  0 816. .30  6  2 .46 .46 .06 200.  5  0     .46
41LRU16   11.0                 1  0 402. .01  6  21.381.38 .06 200.  8  0    1.38
41LRU17   11.0                 2  01448. 2.0  6  2 .63 .63 .06 200.  3  0     .63
41LRU18   11.0                 1  0 188. .50  6  2 .55 .55 .06 200.  3  0     .55
41LRU19   11.0                 1  0 176. .05  6  2 .51 .51 .06 200.  3  0     .51
41LRU20   11.0                 0  01673. .10  6  2 .63 .63 .06 200.  6  0     .63
41LRU21   11.0                 1  0  79. .25  6  2 .46 .46 .06 200.  6  0     .46
41LRU22   11.0                 1  0 402. .01  6  2 .50 .50 .06 200.  3  0     .50
41LRU23   11.0                 1  01673. .25  6  2 .46 .46 .06 200.  5  0     .46
41LRU24   11.0                 1  0 272. .50  6  2 .46 .46 .06 200.  3  0     .46
41LRU25   1.33SRU58  GRD.T.BD  1  0    0. .01  6  2 .40 .40 .06 200.  3  0     .40
41LRU25   2.62SRU59  HV.BD.AY  1  0    0. .01  6  2 .40 .40 .06 200.  6  0     .40
41LRU25   3.05                 4  02340. .50  6  2 .43 .43 .06 200.  1  0     .43
41LRU26   11.0                 1  0 533. .10  6  2 .70 .70 .06 200.  0  0     .70
41LRU27   11.0                 1  0    0. .01  6  2 .33 .33 .06 200.  0  0     .33
99
51SRU53    698.  .5 209. .01  1  0  7 8 1.5 1.5 .33 .41 .41  6  2 .06 200.    .41
51SRU54    674. 2.0 202. .10  1  0  3 8 1.5 1.5 .33 .40 .40  6  2 .06 200.11  .40
51SRU57    544. 5.0 163. .01  1  0  4 2 1.5 1.5 .33 .50 .50  6  2 .06 200.1   .50
51SRU60   1500. 6.0   0. .50  1  0  510 1.5 1.5 .33 .58 .58  6  2 .06 200.    .58
51SRU55    956.  .5 287. .20  1  0  3 2 1.5 1.5 .33 .80 .80  6  2 .06 200.    .80
51SRU56   1628.  .2 488. .01  3  0  610 1.5 1.5 .33 .55 .55  6  2 .06 200.    .55
51SRU51   1030. 5.0 309. 1.0  1  0  3 6 1.5 1.5 .33 .46 .46  6  2 .06 200.    .46
51SRU52    675. 40. 203. 1.0  1  0  3 4 1.5 1.5 .33 .46 .46  6  2 .06 200.    .46
51SRU58   1169.  .5 350. .01  1  0  5 0 1.5 1.5 .33 .40 .40  6  2 .06 200.    .40
51SRU59    905. 1.0 302. .01  1  0  5 0 1.5 1.5 .33 .40 .40  6  2 .06 200.    .40
99
```

Figure 7b.

```
32 LRU02     1001200520065001600560 06
```

Additional input data for the sample problem is as follows:
wholesale change factors
  1.0   1.0   1.0
Pareto change factors
 2002   1.5   6002   1.5 LRU14   1.5   0.75

Figure 7c.

2.2 LRU/SRU/SE Relationships

In order to understand how NRLA works, it is important that the user understand how LRUs and SRUs relate to SE and how these relationships are entered into the program.

Table 2

LRU/SRU/SE Relationships

		Inter			Depot		
		1	2	3	1	2	4
LRU-1		X			X		
LRU-2			X	X		X	X
	SRU-21	X			X		
	SRU-22		X			X	
LRU-3			X	X			X
	SRU-31	X			X		
	SRU-32		X	X			X

Table 2 shows LRU/SRU/SE relationships for a sample problem. LRU 1 has no SRUs associated. LRUs 2 and 3 have associated SRUs. If intermediate repaired, SE-1 is used. If depot repaired, SE-1 is required at depot.

The Xs indicate which SEs are required for repair of LRUs and SRUs. Note that the SE at intermediate and depot need not be identical. Also, note that there is one repair involved if an LRU has no SRUs, namely, the repair of the LRU. If an LRU has associated SRUs, two repairs are involved for each SRU, (1) removing and replacing the SRU from the LRU, called the LRU failure mode repair, and (2) repairing the SRU. A third repair, removing and replacing the LRU from the line item, is not considered, because this repair is identical regardless of how the LRU and SRU are repaired. It is advisable but not necessary that the user prepare such a table. Its exact preparation is described in Section 2.4.1.

It is of interest that the LRU/SRU/SE table is translated into a network by the computer, enabling the system to be solved as a network. Technical details of network construction and solution are given in Appendix 4.

2.3 Input Data File. The input data file for the NRLA program is composed of eight types of data records. The following pages contain a description of the values specified with each type of record, show an example of data forms with sample data, and show the format used to print out the input values.

For all data input a decimal between the characters locates the decimal and indicates floating point format. The user by insertion of a decimal as a character may, where space permits locate the decimal where he chooses.

Where no decimal point is shown between characters, the fields are in fixed point and all numeric entries must be right justified with no decimals permitted as an input character.

Table 1 shows the required and optional entries for Columns 1 and 2 of all eight input records.

The first three records (Figure 1) of the data file must be the weapon system data card, maintenance system data card, and the supply system data card. The data elements contained in these records are normally supplied by the Air Force program office.

Input record separators must be included following input Records 4, 5, 6, and 7, (Figures 2, 3, 4, and 5). A card with 99 in Columns 1 and 2 must be entered to act as a separator. See Figures 7a, b, and c for an example of usage of the "99" card. If SRU data are not to be entered in record 7, a "99" separator card must still be entered to represent the record 7 data. In this case the record 7 "99s" card will follow directly behind the record 6 "99s" card.

Record 8 (Figure 6) is the last data type to be entered.

(1) Weapon System Data. (Figure 1) Data values should reflect a mature (steady state) peacetime level of operations for the weapon system.

1. End-Item Name - alphanumeric end item name to be printed on each output page

2. No. of Bases - the total number of operational locations for the system (each is assumed to have intermediate level repair facilities)

3. Ratio OS - fraction of the total number of systems which are deployed to overseas locations

4. Yr System Life - operational service life of the weapon system in years

5. Equiv. Weapon Systems Per Base - the number of systems operating at each base

6. System Operation Hours Per Month - flying hours per month, operating hours per month

7. SE Development Cost - the cost of developing SE for the system, in $1000 units

8. Sensitivity Alternatives Swept and Extremes Only - sensitivity analysis is available in different combinations:

   '0' No sensitivity performed

   '1' LRU Cost sensitivity only

   '2' SRU Cost sensitivity only

   '3' LRU MTBF sensitivity only

   '4' All types of sensitivity (Types 1, 2, and 3 above)

9. Sensitivity Range - Lower Range (L) is the lower ratio of the range for the item being analyzed. Upper Range (U) is the upper ratio of the range for the item being analyzed. As an example, if an LRU cost $2000 with L = .5, and U = 1.5, the LRU cost would be investigated over the $1000-$3000 range. Similarly for MTBF, for an item with 3000 hour MTBF the range would run from 1500 hr-4500 hr. If no range entry is made, no sensitivity will be performed regardless of the entries under Sensitivity Alternatives.

10. Sensitivity Type - If it is desired to compute the solution for the extremes of the indicated range only, a "0" is entered in Column 54. If complete sensitivity is desired the "1" is entered.

11. Optional Information - If it is desired to identify specific runs, Columns 55-74 may be used. This alphanumeric entry will be printed on the first output page.

(2) Maintenance System Data (Figure 1)

1. Base Shop Man-hours - available work time per month for an intermediate level maintenance man (man-hours/month).

2. Base Labor Rate - hourly labor rate for intermediate level maintenance men ($/hour).

3. Depot Shop Man-hours - available work time per month for a depot level maintenance man (man-hours/month).

4. Depot Labor Rate - hourly labor rate for depot level maintenance men ($/hour).

5. Base Turnover Rate - annual turnover rate for intermediate level maintenance personnel; if personnel turnover every three years, use 0.333.

6. Depot Turnover Rate - annual turnover rate for depot level maintenance personnel.

(3) Supply System Data (Figure 1)

1. Initial Management Cost - initial management cost to introduce a new item (assembly or piece part) into the Air Force inventory system ($/item).

2. Recurring Management Cost - recurring management cost to maintain an item (assembly or piece part) in the wholesale inventory system ($/item/yr).

3. Base Supply Management Cost - annual cost to maintain an item in the base level supply system ($/item/yr).

4. Order and Ship Time CONUS - the elapsed time between the initiation of a request for a serviceable item from the depot and the receipt of the item at a CONUS base (months).

5. Order and Ship Time OS - order and shipping time for overseas bases (months).

6. Packing Cost CONUS - packaging cost for shipments to CONUS bases (including both labor and materials cost) - ($/pound).

7. Packing Cost OS - packaging cost for shipments to overseas bases ($/pound).

8. Packed Wt Ratio CONUS - ratio of packaged item weight to item weight for CONUS shipments (if an item weighs two pounds and its packaged weight is three pounds the ratio is 1.5).

9. Packed Wt Ratio OS-ratio of packaged weight to item weight for overseas shipments.

10. Shipping Rate CONUS - cost for shipping items to CONUS locations ($/pound).

11. Shipping Rate OS-cost for shipping items to overseas locations ($/pound).

12. Tech Data Cost - cost per original page of technical data produced by the contractor to support item repairs. This is the cost of data preparation and excludes reproduction and distribution costs ($/page).

(4) Support Equipment Data Record (Figure 2) Immediately following the supply system data card are data records describing support equipment resources used for item repairs. A data record must be supplied for each kind of SE to be considered for depot use and for intermediate level use.

In order to accurately identify SE resource requirements to the NRLA program it may be necessary for the user to analyze the costs and capabilities of sophisticated multipurpose support equipment. The need for such an analysis can be explained with an example.

Suppose that a particular SE has certain capabilities such that it can be used for the repair of two different LRUs, LRU A and LRU B. Further, suppose that by developing additional software for the SE it can support the repair of LRU C, and that by developing some additional hardware, LRU D can be added to the workload. In this case it would be incorrect to consider the basic SE plus the additional software and/or hardware as a single unit. This is true because the first two LRUs should not be expected to help justify the added expense of software and/or hardware they do not require. Similarly, LRU C should not share the cost of hardware required by LRU D, and LRU D should not share the cost of software required by LRU C.

Representing the basic SE, plus additional software, and additional hardware as a single unit can produce illogical results. Specifically, the NRLA program could recommend the purchase of the SE and recommend a discard decision for LRU C and/or LRU D. Thus, it would recommend a discard decision while simultaneously recommending the purchase of software and/or hardware required only for the discarded items.

To properly enter SE costs, SE must be identified as common, and peculiar, additional hardware, or additional software, each at intermediate and at depot. This enables all four LRUs to share the cost of the basic SE, while LRU C and D can be required to economically justify their own unique support equipment requirements.

At intermediate and depot, for common SE the program first uses available time on existing SE before purchasing additional, if required. For peculiar SE and additional hardware, the program purchases the required items in the required quantities. For additional software, the program purchases only one set, if required. See Sec 2.4.5 for additional comments.

Each SE data record contains the digit '1' in column one. The remaining data items are:

1. SE Ident No. (SEN)– The support equipment identification number is a four digit integer value assigned by the user to each SE resource. It must be entered low to high according to the first digit. The first digit identifies a resource type:

   '1' for common SE at depot, i.e., SE that already exists at the depot for use by items not being analyzed in this repair level analysis.

   '2' for peculiar SE at depot, i.e., SE specifically designed to support the repair of items being analyzed.

   '3' for supplementary hardware (e.g., special adaptors, interconnecting cables, etc.) at depot which augments other SE (common or peculiar) to provide additional repair capability.

   '4' for supplementary SE software at depot, i.e., software which increases the repair capability of automatic test equipment (common or peculiar).

   '5' for common SE at intermediate level.

   '6' for peculiar SE at intermediate level.

   '7' for supplementary hardware at intermediate level.

   '8' for supplementary SE software at intermediate level.

The remaining three digits are arbitrarily assigned but must be unique within each resource type.

2. SE Name - alphanumeric name for the resource, e.g., oscilloscope, LRU tester, etc. Embedded blanks permitted.

3. SE Cost - cost per unit for the support equipment; production costs ($/unit).

4. SE Operating Cost - annual cost to operate and maintain a unit of the resource ($/year).

5. No. of SE - number of existing units of the SE per location (applicable for common SE only).

6. Current Usage - average in-use time for each of the existing SE units (applicable for common SE only) (hours/month).

7. Available Time - expected time (both existing and potential) that a unit of the SE will be available for item repairs (not applicable for SE software) (hours/month).

8. Facilities Cost - total cost of new facilities and/or environmental controls required for the SE (Dollars).

(5) Line Replaceable Unit (LRU) Data Record (Figure 3). The LRU data record contains descriptive data for the first-indenture-level components of the end-item. Each data record has '31' in the first two columns. The remaining data elements are:

1. LRU Ident - user assigned alphanumeric LRU identifier, e.g., LRU work unit code or part number. Embedded blanks permitted.

2. LRU Name - any alphanumeric LRU descriptor (used only for print out). Embedded blanks permitted.

3. Number of LRUs Per End-Item - The number of LRUs per aircraft or other end-item.

4. Unit Cost - unit cost of LRU ($/unit). Note: If the LRU is a rebuilt one using components of an existing LRU, the rebuilding costs should not be used in lieu of a purchase cost. Rather the estimated economic value to the government if purchased should be used. This assures that pipelines will be properly evaluated. This situation implies that the rebuilt item will have a new national stock number. If the rebuilt item will maintain its old stock number, the existing level of repair should be used except if the use under consideration is the only use of the item. If the sole use, then RLA should be performed in the normal fashion and the SMR code of the item changed, if necessary to conform to the new situation.

5. Weight - of the LRU (pounds).

6. Operating Ratio - ratio of LRU operating hours to end-item operating hours.

7. Depot Repair Cycle Time CONUS - the elapsed time from removal of a failed LRU at a CONUS base until the item could become a serviceable spare in depot stock, it includes the time required for base to depot transportation and the depot shop flow time required for repair (months).

8. Depot Repair Cycle Time Overseas - the elapsed time, from removal of a failed LRU at an overseas base until the item could become a serviceable spare in depot stock (months).

9. Base Repair Cycle Time - the elapsed time from removal of a failed LRU at a base until it could become a serviceable spare in base stock (months).

10. Repair-in-Place - fraction of LRU failures which can be repaired at the organizational level (on-equipment maintenance).

11. No. Kinds of GPSE Reqd - the total number of kinds of general purpose (GP) SE resources (depot and base) associated with LRU repair; if one type of SE would be required for depot repairs but two types required for intermediate level repairs this value should be 3. GPSE is SE used on every failure mode of the LRU in question. A particular SE should not be listed as both GPSE and SPSE for a given LRU. Refer to Section 2.4.1. This entry must match the number of SE resource numbers entered on a corresponding record 8 ('32' in first two columns).

12. MTBF - mean time between failures for the item in its operational environment. This is the derated MTBF (operating hours)

(6) LRU Failure Mode Data Record (Figure 4). Individual data records are used to provide data for each failure mode of each LRU. If an LRU has SRUs, there should be one record for each SRU of the LRU to provide information about the LRU repair tasks which involve removing and replacing a failed SRU. Additionally, one or more records may be required to provide information about LRU repairs which do not involve removing and replacing an SRU. If the LRU has no SRUs, there must be at least one LRU failure mode data record corresponding to the repair of the LRU. Each data record has '41' as its first two characters. All failure modes of a particular LRU must be grouped together. The remaining data elements are:

1. LRU Ident - user assigned alphanumeric LRU identifier, the value must match the corresponding entry on a type '31' data record, including embedded blanks if any.

2. Failure Mode Ident No. - a user assigned 2 digit integer value used to distinguish the different failure modes for an LRU.

3. Failure Mode Ratio - the expected frequency of this type of failure as a fraction of all failures for the LRU.

4. SRU Ident - user assigned alpha numeric identifier for the SRU associated with this failure mode (if any). This identifier may include embedded blanks.

5. SRU Name - any alphanumeric SRU descriptor (used only for print out).

6. No. New Parts - the number of new piece-parts and/or assemblies required for the repair (new items are those not already in the Air Force inventory system.) If applicable, this number should include the SRU.

7. No. Std. Parts - number of standard (already stock numbered in AF inventory) items which will have to be entered into the base inventory system if the LRU is base repaired. If applicable, this number should include the SRU.

8. Repair Parts Cost - total cost of all non-reparable assemblies and/or piece-parts required for repair of this fialure mode, this cost does not include the cost of the SRU associated with the failure mode (Dollars).

9. Weight of Piece-Parts - total weight of all non-reparable assemblies and/or piece-parts required for repair of this failure mode (pounds).

10. No. Persons Trained at Depot - minimum number of depot maintenance personnel to be trained for the repair task, this failure mode only. (This entry is optional.)

11. No. Persons Trained at Base - minimum number of intermediate level maintenance personnel to be trained for the repair task, this failure mode only. (This entry is optional.)

12. Depot Maintenance Man-Hours - the number of maintenance man-hours required for repair if the repair is done at the depot (man-hours/repair).

13. Base Maintenance Man-Hours - the number of maintenance man-hours required for repair if the repair is done at intermediate level (man-hours/repair).

14. Training Time - maintenance training time required to teach the skills and/or procedures for performing the repair task (weeks).

15. Training Cost - the expected cost for the required training (instruction and materials) ($/week/person).

16. Tech. Data Pages - the number of technical data pages required for the repair task (No. pages/repair).

17. No. SP SE Reqd - the total number of special purpose (SP) SE resources (kinds of SE). If none is required, '0' need not be entered. If an SPSE is used on other failure modes of the same LRU it must be entered for these LRU failure modes individually. A particular SE should not be entered as both GPSE and SPSE for a given LRU. Refer to Section 2.4.1. This entry must match the number of SE resource numbers entered on a corresponding record ('SE' in first two columns).

18. Forced LRU Failure Mode Decisions - It is possible to force an LRU into a particular decision for comparison purposes. If a 1 is entered into columns 74, 75, or 76 then Depot, Scrap, or Base respectively will be excluded for the failure mode. If a 1 is entered into any two of the columns both repair levels will be excluded forcing the decision to the one with no entry. If all three columns have an entry, this will be considered an error. The 1's will be changed to 0's, a message will be printed, and the program will proceed as if no exclusions were desired for the particular item.

19. SE Hours per Repair - the number of hours the SE is needed to repair the failure mode. (hours/repair)

(7) Shop Replaceable Unit (SRU) Data Record (Figure 5). This record is used to specify the data elements required for computing SRU related repair level decision costs. If multiple failure modes have been identified for an SRU then the individual data values should be for the dominant SRU failure mode. Early in the program users may choose to omit this record until more data becomes available. The hazard of omitting the record is misapplication of the SE. It would be better to estimate the SRU data and include it; then update as information becomes available. Each record has 'S1' as its first two characters. The remaining data elements are:

1. SRU Identifier - seven place alphanumeric identifier of the SRU. This value must match the corresponding entry on a type '41' data record including embedded blanks, if any.

2. Cost of SRU - unit cost of the SRU ($/unit).

3. Weight of SRU - (lb/SRU).

4. Cost of Piece Parts and Assys Per SRU Repair - dollar value of piece parts and assemblies used to repair the SRU ($/SRU Repair). This is the weighted average cost of the parts required to repair the SRU. If two components of the SRU are involved and component 1 cost $10 and causes 20% of the SRU failures and component 2 cost $50 and causes 80% of the failures, then the weighted average cost of the piece parts is (.2 x $10) + (.8 x $50) = $2 + $40 = $42.

5. Weight of Parts and Assemblies - weight of piece parts and assemblies used in above description (lb/SRU repair).

6. No. of New Piece Parts and Assemblies Used - new means new to the Air Force inventory. (No. Parts and Assys/SRU Repair).

7. No. Std Piece Parts/Repair - Standard means already existing in the Air Force inventory. However, these parts are new at the base and will be used for repair of the SRU (No. Parts and Assys/Repair).

8. No. Pages of Tech Data/Repair - the number of technical data pages required for repair (No. Pages/Repair).

9. No. Kinds of SE Used/Repair - this entry must match the number of SE resource numbers entered on a corresponding record 8 ('52' in first two columns).

10. Depot Repair Cycle Time CONUS - the time from removal of a failed SRU from the LRU at the base until it is repaired and ready to be shipped (months).

11. Depot Repair Cycle Time OS - the elapsed time from removal of a failed SRU from the LRU at a CONUS base, until it is repaired and ready to be shipped (months).

12. Base Repair Cycle Time - the time from SRU removal from the LRU at base until it is repaired at base and ready to use (months).

13. Depot Maintenance Man-Hours/Repair - the time required for repair at depot (hours).

14. Base Maintenance Man-Hours/Repair - the time required for repair at base (hours).

15. Depot Trainees - No. persons to be trained at depot, this SRU. (This entry is optional.)

16. Base Trainees - No. persons to be trained at base, this SRU. (This entry is optional.)

17. Maintenance Training Weeks - time it takes to train a repairman (weeks).

18. Maintenance Training Cost - the cost of instruction and materials to train a repairman ($/person/week).

19. Forced SRU Decisions - See discussion of Forced LRU Decisions (Input Record 6). Columns (74), (75), and (76) will be used for Depot, Scrap, and Base respectively.

20. SE Hours per Repair - the number of hours the SE is needed to repair this SRU. (hours/repair)

(8) LRU/SRU/SE Cross Reference Table (Figure 6). This input associates the various LRUs, LRU failure modes, and SRU's with the required SE.

1. Record Type Identifier - Col. 1, enter '3' if LRU/SE relationships are being entered, '4' if LRU failure mode/SE relationships, and '5' if SRU/SE relationships. (Col. 2 must have a '2' entry.)

2. LRU or SRU identifier - These contain the LRU or SRU Identifier and must match, including embedded blanks if any, the alphanumeric identifiers used on cards 5, 6, or 7.

3. Failure Mode - If columns 1 and 2 contain '42' enter the appropriate failure mode from card 6. Otherwise leave blank.

4. SE Resource Numbers - The next 16 fields contain four digit SE identification numbers matching those entered on the SE data records. These relate LRUs, SRUs, and LRU failure modes to the support equipment required to repair them at Intermediate and Depot. They may be entered in any order.

2.4 Additional Data Entry Explanations

2.4.1 Entering LRU/SRU/SE Relationships: Certain data from input records 4, 5, 6, 7, and 8 must be coordinated in order for the program to operate properly. Input record 4 lists the SE available for use. Records 5, 6, and 7 list LRU's, LRU failure modes, and SRU data, respectively. Included on these records is a count of the SE types required for the repair.

Record 8 expresses the relationships between LRUs, SRU's, and SE. If Record 8 shows that a particular LRU or SRU requires a particular type of SE, then that SE should have been listed on Record 4. If an LRU or SRU is listed on Record 8, details concerning it should have been listed on Records 5, 6, or 7.

Before the user begins data preparation, this section should be carefully read and understood. Entering LRU/SRU/SE relationships has been the major cause of user problems. Differentiation of GPSE and SPSE has been a particular source of misunderstanding.

Examining Table 3, in case 1a, an LRU has one failure mode and no related SRUs. One '31' card is entered showing no GPSE. All the SE is related to the failure mode; therefore, the '41' card shows the SE. The number of SPSE entered in the '41' card is simply the sum of the number of Xs in the row, or 2.

Case 1b shows an alternate means of entering the same data. Here the SE is related to the LRU rather than the LRU failure mode. In this case, the '31' card has a 2 entered as GPSE and the '41' card a 0 entry. Again, the sum of the number of Xs determines the entry. The reason that cases 1a and 1b input identical information is, that the definition of GPSE is that it is used in each and every failure mode. Here there is only one failure mode; therefore, cases 1a and 1b are alternate means of entering the same data.

Similarly, cases 2a and 2b are alternate means of entering the same data. In case 2a, SE-2 is related to the individual failure modes; therefore, it is SPSE. In case 2b, since the SE is used in each and every failure mode, the SE information may be entered as GPSE.

In most cases, a failure requires SE to effect the repair. When this happens, a '42' card must be entered for each '41' type card, and a '32' card may be entered for each '31' type card. By designating the SE as GPSE, the number of data entry items is reduced. This is the sole purpose of the GPSE and SPSE designations. As an example, if the GPSE designation did not exist and an SE were required for each and every failure mode, then with 10 failure modes, 10 type '42' cards would be required. By designating these SE as GPSE, entering the data on the '31' card, and entering a matching '32' card, ten '42' cards are omitted, and one '32' is added reducing the number of entry cards by nine.

Table 3
GPSE and SPSE Relationships

Case				Inter SE				Depot SE				Card		Card	
	LRU	LRU FM	SRU	1	2	3	4	1	2	3	5	Type	Entry	Type	No. Entries Required*
1a	1											31	0	32	0
		1		X				X				41	2	42	2
1b	1			X				X				31	2	32	2
		1										41	0	42	0
2a	2											31	0	32	0
		1			X				X			41	2	42	2
		2			X				X			41	2	42	2
		3			X				X			41	2	42	2
2b	2				X				X			31	2	32	2
		1										41	0	42	0
		2										41	0	42	0
		3										41	0	42	0
3a	3											31	0	32	0
		1			X				X			41	2	42	2
		2			X				X			41	2	42	2
		3		X	X		X		X		X	41	5	42	5
3b	3				X				X			31	2	32	2
		1										41	0	42	0
		2										41	0	42	0
		3		X			X				X	41	3	42	3
4	4					X		X			X	31	3	32	3
		1			X				X			41	2	42	2
		2			X				X			41	2	42	2
		3			X				X	X		41	3	42	3
		4		X								41	1	42	1
			1			X		X			X	51	3	52	3
			2.		X				X			51	2	52	2
			3	X	X	X	X	X	X	X	X	51	8	52	8

*Note that if "0" entries are required on a '32' card, no card need be entered. Similarly, if "0" entries are required on a '42' card, no card need be entered.

Cases 3a and 3b again show alternate means of entering identical data. Notice by calling SE-2 at intermediate, GPSE, and entering the data on '31' and '32' cards, two '42' cards may be omitted. Where there are additional [illegible] GPSE for an LRU, there is no reduction in '42' cards entered, but there is a reduction in the number of entries on the '42' card.

Case 4 shows an LRU with four failure modes and three SRUs. Data entries should be made in '31', '32', '41', and '42' cards independent of the SRUs. SRU entries should then be made independently of the LRU and LRU [illegible]. Even if an SE has been designated as a GPSE, [illegible] SE [illegible] entry must be made.

Perhaps the simplest approach for a new user is to prepare a table such as the one displayed, and enter Xs where the LRU failure modes and SRUs use SE. If there appears to be a significant reduction in data entry, by converting the SE used in each and every failure mode for an LRU to GPSE, this can then be done. By preparing such a table, the user has an opportunity to think through the relationships. After the data has been run on the computer, the user can check his manually prepared table against the computer printed table, as shown in Figure 11 of the NRLA guide. Figure 7C is sample data ready for computer input.

2.4.2 <u>One Type of SRU in Several LRUs:</u> When this situation occurs, the user should enter the SRU data into each of the LRUs as if the SRUs did not exist in the other LRUs and run the program. This will entail unique identification of the SRU with respect to each LRU in which it occurs. If the SRUs at issue all are selected for the same level of repair, the issue is resolved, and no further computations need be made. This is very likely to occur since identical SE is used by the SRU. Once the SE is *justified for depot or intermediate*, all the SRUs using it will have a tendency to be assigned to the same location. Only if the SE is justified for both locations is a split apt to occur. In this case, the SRU from one LRU might have a different repair level selected than the SRU from another LRU.

If this happens, the users should use the forcing procedure, forcing all the SRUs into intermediate, then depot, then scrap in three separate computer runs. Total costs can then be examined to determine the preferred repair level.

2.4.3 <u>Multiple SRUs of One Kind in an LRU:</u>

Multiple SRUs in an LRU may be handled as described below. Table 4 shows two situations, (a) the usual situation and (b) multiple SRUs in an LRU. Suppose that in situation Table 4 (a) SRU-1 and SRU-2 are identical each causing 25% of LRU-1's failures. This situation of multiple SRUs in an LRU can be modeled by NRLA as in situation Table 4 (b). Note the data for SRU-1 is entered once (one 41 card and one 51 card) but it now has a failure mode ratio double its previous value. No other changes need be made. The modified failure mode ratios are entered on data record 6, the LRU failure mode card (41 card). Note that the cost of the SRU should not be changed since pipeline costs relate to the cost of an individual SRU, not the multiple SRUs in the LRU.

2.4.4 <u>Number of Persons Trained:</u> These entries on the LRU failure mode and SRU records (cards 7 and 8), for both depot and intermediate, are optional. The program calculates the SE values and rounds them up. If there is no user entry, the program computed values are used. If the user enters one or more values, the user entered values are compared to the computed values, and the higher of the two is used in calculation of maintenance training costs. See equations 74 and 76 of Appendix 3.

2.4.5 Differentiating Among SE Types: SE may be categorized as depot 1..., 2..., 3... or 4... or intermediate 5..., 6..., 7... or 8.... If SE is entered as type 1 or 5, existing SE is used for any available time, before additional SE is purchased. Types 2 and 3, and 6 and 7, are identically treated. If any hours of these types of SE are used, the SE must be purchased. The program treats types 2 and 3 identically. The distinction between them was originally intended to help the user clarify his thoughts. When priorities permit, these two categories will be combined into one. The same comment applies to types 6 and 7. If necessary, more than one SE of types 1, 2, 3, 5, 6, or 7 will be purchased.

Types 4 and 8 are intended to represent associated SE software or development costs. Since only one set of software or development is purchased, the program will indicate that either none or one set is to be purchased.

Table 4

Two Possible NRLA Situations

		No. SRUs/LRU	No. 41/51 Cards	Failure Mode Ratio
(a)	Usual Situation			
	LRU-1			
	SRU-1	1	1	.25
	-2	1	1	.25
	-3	1	1	.20
	-4	1	1	.30
	Totals	4	4	1.00
(b)	Multiple SRUs in an LRU			
	LRU-1			
	SRU-1	2	1	.50
	-3	1	1	.20
	-4	1	1	.30
	Totals	3	3	1.00

2.5 Data Preparation Summary. When preparing data, especially the first time, the user should consider that Table 3 is the heart of understanding data preparation. Data Records 1, 2 and 3 represent system wide data and usually present few problems to the new user. Data Records 4, 5, 6, 7 and 8 are derived from Table 3.

2.5.1 Data Record 5 - For every LRU listed vertically at the side of the table, a description of the LRU must be entered. This is done on Data Record 5 (the '31' card).

2.5.2 Data Record 6 - A description of each failure mode listed in the table must be entered. This is done on Data Record 6 (the '41' card).

2.5.3 Data Record 7 - A description of each SRU item listed on the table must be entered. This is done on Data Record 7 (the '51' card).

2.5.4 Data Record 4 - A description of all the SE used in the problem must be entered. The SE are listed across the top of the table for both depot and intermediate SE. The SE descriptions are entered on Data Record 4.

2.5.5 Having entered descriptions of the respective SE, LRU's, LRU failure modes, and SRUs on the respective Data Records 4, 5, 6, and 7, it is necessary to enter the LRU/LRU failure modes/SRU/SE relationships. These are represented by the Xs in the table. The Xs are translated by the computer program into a network, which is solved to determine the optimum solution. These Xs are entered into the computer program using Data Record 8 (the 32, 42, or 52 card). In essence, each entry in the groups of columns beginning 13, 17, 21. . . . represents an 'X'.

If the user indicates SE at one location but fails to indicate the SE at the other location, the algorithm will probably select the level of repair without the SE, since it will likely be a less expensive solution than a solution with the SE. If intermediate and depot are feasible solutions, proper SE must be entered at both locations. If the user wishes to exclude a repair level, the proper exclusion levels should be entered on LRU failure mode or SRU cards.

2.6 Types of Sensitivity Analysis

Sensitivity Analysis (SA) is performed in order to investigate affects due to (1) incorrectly estimated data, (2) process changes, and (3) to determine areas of investigation which may be most useful, or (4) to answer " what if" questions. The user may then use the sensitivity information as a rationale for improving estimates, selecting projects for further developmental work, or doing nothing, as the particular situation warrants.

Four types of SA will be discussed. These are Swept, Extremes Only, Wholesale, and Pareto. Swept and Extremes Only sensitivity may present difficulties in large problems. Computer run time or output may be excessive, either making the program expensive to run or the output difficult to interpret because of its volume. Computer run time is a function of the number of times the network must be solved. Difficulties of interpretation are related to the numbers of solutions which must be interpreted. Neither is directly related to the amount of printed output. Wholesale Changes (WC) and Pareto analysis are intended to shorten the SA process in terms of both computer time and output.

2.6.1 Sensitivity Assumptions. The LRU unit cost sensitivity analysis makes the assumption that as the LRU cost increases or decreases there are corresponding cost changes for the LRU repair piece parts and for the SRUs within the LRU. Thus, if the LRU doubles in cost then the cost of piece parts required for repair doubles and the cost of each SRU (if any) also doubles.

A different assumption is made for the SRU cost sensitivity. Here it is assumed that a change in LRU cost occurs solely because of a change in the cost of one SRU. Consequently, if the SRU cost doubles then the LRU cost increases by the dollar amount of the SRU cost change.

The assumption for the LRU MTBF sensitivity is that the total number of LRU failures changes, but the proportion of failures of each type remains constant. That is, the relative frequency of the different failure modes remains unchanged. The case where the LRU MTBF changes because one of its SRUs fails more (or less) frequently is not treated. Also not treated is the case where the LRU failure rate does not change but the relative frequencies for the different failure modes do change.

2.6.2 Sensitivity Range: The user selects the ranges at which the sensitivity is to be performed. As an example, he might choose LRU MTBF at 50% and 200% of the baseline case.

2.6.3 Swept Sensitivity

Swept sensitivity is so called because once the range of investigation is selected, the program sweeps through the range, one LRU or SRU at a time. As an example, if MTBF for an item is estimated to be 500 hours, and the range being investigated is 50% to 200%, each change in repair level is noted as MTBF changes from 250 hours to 1000 hours. If no changes in repair levels are noted in the vicinity of the 500 hour MTBF baseline, the situation is considered to be insensitive.

When the entire range is investigated a search is performed for all points at which SE and/or LRU and SRU decision changes occur. The search for a decision change point terminates when the program has determined a relatively small range such that some change occurs within the interval. The interval width has been arbitrarily set to be 1% of the input LRU cost for the LRU and SRU cost sensitivities; and to be 1% of the input MTBF for the MTBF sensitivity. Specific assumptions are incorporated into the analyses.

If repair levels change when small changes in MTBF take place, the model is considered to be sensitive. Precise definition of the boundary between a sensitive and insensitive model must depend upon the user's system and needs. IRLA uses swept sensitivity. Since IRLA considers one LRU or SRU at a time, changes in repair levels of one item do not ordinarily affect other items. However, since NRLA considers the whole system at one time, repair level changes occurring during SA can successively affect other items throughout the system, possibly making the SA extremely complex.

Therefore, swept sensitivity may be used on small NRLA problems, but computer time and numbers of network solutions to be interpreted may quickly become excessive if this approach is used for larger NRLA problems.

2.6.4 Extremes Only Sensitivity

With extremes only sensitivity, only two levels, the lower and upper extremes, are investigated. As an example, if there were three LRUs and the selected range for MTBF were 50%-200%, the NRLA program would give results as each LRU-MTBF was sequentially changed to the extreme of the ranges selected. The network would be solved up to six times (two solutions per LRU or SRU) in addition to the baseline case. Table 5 lists the input for six network variations that would be solved.

TABLE 5

INDIVIDUAL CHANGE MTBF FACTORS

	INPUT VARIATION					
	1	2	3	4	5	6
LRU 1	50%	200%	100%	100%	100%	100%
LRU 2	100%	100%	50%	200%	100%	100%
LRU 3	100%	100%	100%	100%	50%	200%

If LRU cost and MTBF were being investigated, up to 12 outputs would be produced, six for each of the factors being investigated. If 60 LRU/SRUs were being investigated, up to 240 outputs might be produced:

60	x	2	x	2	=	240
LRUs/SRUs	x	outputs / factor	x	No. Factors investigated	=	outputs

The words "might be produced" are used since if no changes occur at the extreme being investigated, only a message is produced. NOTE: The number of computer runs may be different than the number of outputs, since output is only produced if repair levels selected are different from the baseline.

This type of investigation for a large NRLA problem though quicker than swept sensitivity, may still use excessive computer time and produce excessive output.

2.6.5 Wholesale Changes (WC) Sensitivity is similar to extremes only, except that all changes for a given factor are made at once. However, since doubling or halving all costs or MTBF at once is rather extreme, the sample range for WC is 80 - 125%. The user should select a realistic WC range in keeping with the nature of this system. For the three LRUs used earlier, see Table 6.

TABLE 6

WHOLESALE CHANGE

MTBF RANGE FACTORS

INPUT VARIATIONS		
	1	2
LRU 1	80%	125%
LRU 2	80%	125%
LRU 3	80%	125%

Instead of up to six outputs, only two are produced. Thus, if LRU cost and MTBF, and SE costs were being investigated, exactly six output reports would be produced, two for each factor, regardless of how many LRU/SRUs or SE were in the system being investigated. The justification for making such "wholesale" changes is that the user is less interested in the repair policy for any particular LRU or SRU than the affect on total system costs.

If a group of changes are made simultaneously in one direction, e.g., doubling the cost of all LRUs, and the system cost or the repair levels selected do not change significantly, we may conclude that any one of the LRU costs if doubled, would have even less of an affect. We would have avoided the need for individual change sensitivity for all items. If there is an interest in a particular variation of a particular LRU or SE, this can be set up for a special computer run.

If the system cost of the whole-sale changes is significant or the repair levels selected are very different, the user should perform a Pareto analysis to determine the most significant items with regards to sensitivity.

2.6.6 Pareto Analysis

Pareto Analysis is performed in a fashion similar to extremes only. The major difference is that instead of all LRUs, SRUs, and SE being individually investigated with regard to sensitivity, only the highest cost or lowest MTBF items are investigated. Using Pareto analysis, the user can determine exactly how much computer time he can afford, how much output he wants, and can tailor the investigation to his resources. To show the advantage of the Pareto approach, Table 7 was prepared.

We call the various situations baseline (BL), the originally projected levels; Pessimistic (Pess), some situation worse than the Baseline; and Optimistic (Opt), some situation better than the Baseline.

Table 7 is the result of an extremes only (Pessimistic and Optimistic) investigation of the individual LRU MTBF (upper part) and LRU costs (lower part). The left hand group of columns gives the MTBF or LRU cost, system cost, and percent of baseline cost of the optimistic extreme. The center columns list the Baseline MTBF and system cost. The right hand columns list the pessimistic MTBF or LRU cost, system cost, and percentage of baseline.

In the center columns, the baseline NRLA computer run had a system cost of $10,791,600. The respective baseline MTBF and cost/LRU are shown. If LRU-1 MTBF changes from 775 hours (Baseline), to 1550 hours (Optimistic) and no other changes are made, the altered system costs $10,664,000 to operate, or 99% of the baseline value. The "all" rows show the system cost if all MTBF or LRU costs were simultaneously changed. Thus in the baseline columns, an 82 hour MTBF is the composite MTBF of all five LRUs taken together and $216,060 is the cost of all five LRUs.

To prepare Table 7, 25 computer runs were necessary, one for the baseline and 12 each for Optimistic and Pessimistic levels.

Using the Pareto method, only the worst MTBF and cost items would have been selected for investigation. In this case, LRU-5 (MTBF) and LRUs 2 and 5 (Cost) only might have been selected. Seven computer runs would have been made, Baseline, Optimistic, and Pessimistic MTBF for LRU-5 and optimistic and pessimistic costs for LRUs 2 and 5. Comparing the computer runs that would have been selected for Pareto analysis with the other ones, we note that the worst MTBF and LRU cost items had the greatest effect on system cost. Had we examined these only, we would have determined the sensitivity of system costs to changes in LRU cost and MTBF of these items. We would have gained the most important information with 7 computer runs instead of 25. Note that for LRU-5, system costs are much more sensitive to MTBF than cost variation. Doubling the cost of LRU-5 causes a 7% increase in system cost. Halving the MTBF causes a 44% increase in system costs. Improving or controlling the MTBF of LRU 5 is significantly more important than reducing or controlling its costs. An opportunity presents itself to invest money in the LRU, increasing its necessary costs if the MTBF could be significantly improved. This analysis applies to the sample problem only. Each problem would require individual analysis. The example describes a Pareto analysis for LRU MTBF and costs. A similar Pareto analysis should be performed for SE costs.

[illegible]

Individu[illegible] [illegible]

[illegible]								
	[illegible]			[illegible]		[illegible]		
LRU	MTBF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	2,5[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible],[illegible]22	96.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible],4[illegible]	96.	[illegible]	[illegible],79	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	164	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]								
[illegible]	[illegible]	Tot. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The value of Pareto analysis is reduced computer run time and sensitivity output. It enables the user to focus on the important problems and not become lost in excessive analysis of probable low utility.

2.6.7 Sensitivity Variations: Table 8 summarizes the sensitivity variations available without changing the baseline data.

Table 8 - Standard Sensitivity

	Swept	Extremes Only	Wholesale	Pareto
LRU Cost	X	X	X	X
SRU Cost	X	X		
LRU MTBF	X	X	X	X
SE Cost			X	X

Multiple Runs. Because the program investigates a limited number of variations the user may wish to make multiple runs. It may be necessary to investigate the effect of different end-item utilization rates, repair cycle times, or different support equipment configurations and requirements. Additionally, joint sensitivities may be calculated in which costs or MTBFs change simultaneously for a group of items. Further, the effect of higher unit cost coupled with higher MTBF could be examined, as well as the highly undesirable situation of higher cost coupled with a lower MTBF.

2.6.8 Sensitivity Analysis Strategy

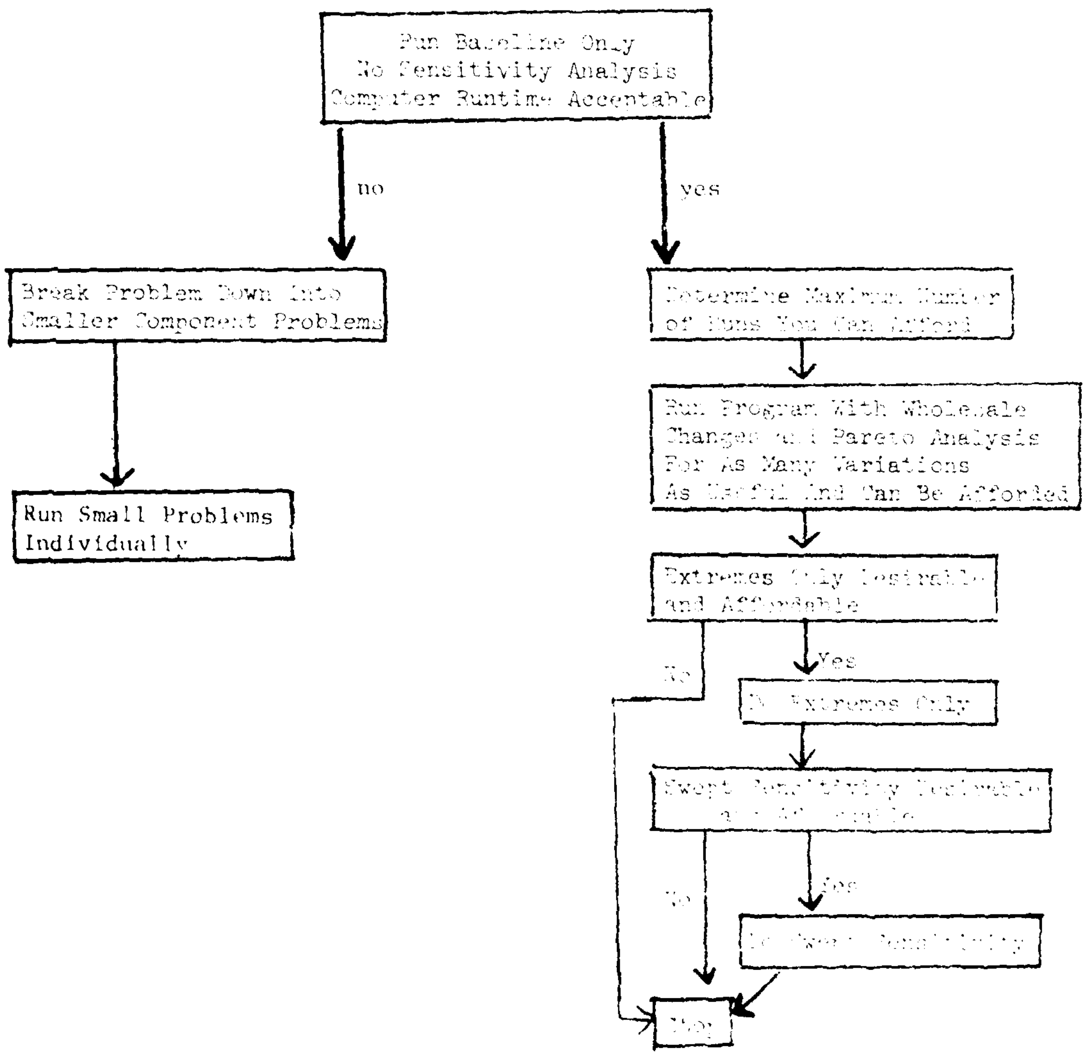
Sensitivity analysis for NRLA should not be performed blindly or by rote. Rather the user should perform a step-by-step investigation at each stage carefully determining the cost and probable benefits of continued investigation. Figure 8 shows a suggested diagram of a NRLA sensitivity analysis. Notice that at every phase of analysis the user reevaluates where he stands and the value of continuing the investigation. He should not blindly use computer power, to generate voluminous output, of questionable use, at potentially high cost.

In determining whether to continue the investigation, the user should estimate how many times the NRLA program will have to solve the network and the estimated computer time or cost. This is relatively easy except for swept sensitivity. He should also note the expected volume of output, and whether or not SA already produced yields sufficient information to warrant stopping. In general, swept sensitivity and possibly extremes only, will be prohibitively costly for large problems.

The computer run time can be estimated by solving the problem once with no sensitivity. The CPU time would be a conservative estimate of the network solution time. In a problem of any magnitude, solving the network takes the bulk of the time compared to the input and output.

FIGURE 8

SENSITIVITY STRATEGY



2.6.9 Wholesale Changes and Pareto Program Operation

Individual Change (IC) Capability is the ability to apply a factor to any individual LRU MTBF and/or LRU and SE cost. Thus a specific LRU MTBF can be multiplied by any factor. This ability is used for Pareto analysis for a selected list of items. When making WC or Pareto computer runs, cards 9 and 10 shown as Table 9 must be used. Use of these cards is described in Table 9.

Table 9 - Individual and Wholesale Change Entries

CASE	TYPES OF CHANGES	CARD 9	CARD 10
1	Individual Changes Only	Blanks or 1.0's	IC Factors
2	Wholesale Changes Only	Enter Factors	None
3	Individual & Wholesale Changes	Enter WC Factors	Enter IC Factors

It is unlikely that the user will want to run Case 3. If he does the WC and IC factors both apply.

Card 9 (Table 10) Wholesale Change Factor Card. This card has three entries. The first multiplies all LRU and LRU piece parts costs and SRU and SRU piece parts costs, the second multiplies all LRU MTBFs, and the third multiplies all SE costs. Any combination of positive factors is possible. If a baseline case is desired, simply use 1.0 for each multiplier entry.

Card 10, (Table 10) Individual Change Factor Card. This card has seven fields. The first two pairs are for SE resource numbers and the desired change factor. Pairs of entries are given so that the user can change SE costs both at Intermediate and at Depot with one card. It does not matter whether depot or intermediate data is entered in a particular set of columns. The SE Resource number instructs the program as to which it is. The fifth field is for the LRU identifier (work unit code) and must match columns 4 to 10 of the LRU data card. The sixth and seventh are for LRU cost and MTBF factors.

Table 11 gives a sample of 15 runs to illustrate use of the sensitivity analysis feature. Notice that data for each run is begun with a Card 9 and ended with a 99999 card. Variable data may be entered in the Card 9 and the Card 10 where used. Runs 1-6 illustrate wholesale changes. LRU costs, MTBF, and SE costs are successively doubled and halved. These are the six variations discussed earlier which yield a large amount of information in six runs. Runs 7-14 illustrate Individual Changes. These are used for Pareto analysis. Runs 7 and 8 double and half SE costs for SE 2001 and 6001. Runs 9-12 double and half costs for the indicated LRUs. Runs 13 and 14 double and half MTBF for the indicated LRU. Run 15 doubles the cost of SE 2001, doubles the cost of LRUs C4581 and C4586 and halves the MTBFs. It illustrates how multiple changes can be made on one computer run. These changes to individual factors, Runs 7-15, are performed to determine the individual effects on costs and repair levels.

Since each computer system may accept data input in a slightly different manner, the description of the data input process for wholesale changes and individual changes is given in general terms only. The user must adapt the input to his specific computer system.

If the user is making wholesale changes, then data records (Card 9) as in Table 12a must be prepared. One data record (one Card 9 followed by a 99999 Card) must be entered and run at a time.

If it is desired to do individual changes, then Card 9 with ones inserted must be entered followed by one or more Card 10's. (Table 12b). If more than one Card 10 is entered, then all the changes will become part of the run.

Tables 12a, b and c show the data of Table 11 as it would be listed for actual data entry. Table 10 is a data form suitable for reproduction.

Table 10

WHOLESALE CHANGE FACTORS

LRU COST FACTORS	LRU MTBF FACTORS	SE COST FACTORS

SE RESOURCE NO. 1	CHANGE FACTOR NO. 1	SE RESOURCE NO. 2	CHANGE FACTOR NO. 2	[illegible]	LRU COST CHANGE FACTOR	LRU MTBF CHANGE FACTOR	INDIVIDUAL CHANGE FACTORS (Note that LRU Work Unit Codes and SE Nomenclature must exactly match listings on Figures 4 & 5.)

[illegible]

[illegible] *

[illegible]	[illegible]			[illegible]			
	[illegible]	[illegible]					
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]	[illegible]	[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]					
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				
	[illegible]	[illegible]	[illegible]				

* [illegible] given [illegible] cause [illegible] terminal system.

Table 12a

SAMPLE RUN SETUPS FOR DATA ENTRY

125	1ØØ	1ØØ	
99999			
8Ø	1ØØ	1ØØ	
99999			
1ØØ	125	1ØØ	
99999			
1ØØ	8Ø	1ØØ	
99999			
1ØØ	1ØØ	125	
99999			
1ØØ	1ØØ	8Ø	
99999			
1ØØ	1ØØ	1ØØ	
2ØØ1	1.25	6ØØ1	125
99999			

Table 12b

1ØØ	1ØØ	1ØØ	1ØØ			
2ØØ1	.8Ø	6ØØ1	8Ø			
99999						
1ØØ	1ØØ	1Ø				
				C4581	2ØØ	1ØØ
99999						
1ØØ	1ØØ	1Ø				
				C4581	5Ø	1ØØ
99999						
1ØØ	1ØØ	1Ø				
				C4586	2ØØ	1ØØ
99999						
1ØØ	1ØØ	1Ø				
				C4586	5Ø	1ØØ
99999						

Table [illegible]

1Ø	1Ø	1Ø		C4581	1ØØ	2ØØ
99999						
1Ø	1Ø	1Ø		C4581	1ØØ	5Ø
99999						
1Ø	1Ø	1Ø		C4581	2ØØ	5Ø
2ØØ1	2Ø			C4586	2ØØ	5Ø
99999						

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3. Program Output

3.1 General - There are eight types of output. They contain data input, intermediate results, supplementary information, the optimal solution and sensitivity analysis. These may be mixed in the output, so that closely related information is presented together.

Input types (1), (2), and (3) (Figure 1) are printed on Ouptut (1) (Figure 9), General Information. Input (4) (Figure 2) is printed on Output (2) (Figure 12), Computed SE Costs. Inputs (5), (6), and (7) (Figures 3, 4, and 5) are printed as part of Output (7) (Figure 14), Repair Level Decision Details. Input type (8) is printed in modified form on Output (3) (Figure 11).

The LRUs are printed in the order of input on Record 5. The associated LRU failure modes are printed immediately following the LRU and are in the order of input on Record 6. The associated SRUs are listed directly following the LRU regardless of the order of input on Record 7. The SE are listed in the order of input on Record 4. Where the output simply lists the input the user should refer to the input descriptions for added detail not shown with the output description.

3.2 System Factors. Figure 9 lists in three columns the data from input records 1, 2, and 3. The listings are in the same sequence as the input record. See 2.3 Input Data File for an explanation of this output.

3.3 Support Equipment Input Values. Figure 10 lists the same information as given on input record 4 in SE code sequence.

3.4 SE to LRU/SRU Relationships.

Figure 11 shows data originally input as record 8. Horizontally across the top in sequence the SE codes are given. Vertically the LRU and SRU names and identification numbers are given. An X in the body of the table indicates that if an LRU has failed in a particular failure mode or an SRU has failed, the intersecting SE must be used for the repair at depot or base, respectively.

In addition to the basic data relating LRUs and SRUs to SE, data related to use of the SE is included for information. In Figure 11, the reference numbers correlate with the following items. They consist of (1) the Repairs/Month of the LRU, (2) the percent failures by failure mode, and (3) the Repairs/Month of the LRU in each of its failure modes. Also contained are the number of hours/month the SE would be used at base and depot if assigned by the respective (4) LRU failure modes, and (5) the SRUs.

In understanding this output it is important that the user recall the meaning of a failure mode. When an LRU fails, it is assigned to SE to determine the fault and to repair the LRU. The repair consists of removing and replacing an SRU. Thus, the LRU used a set of SE for repair. When the SRU is repaired, it is assigned to a set of SE for its repair, thus, two sets of SE may be involved for each failure mode, (1) a set for repair of LRU and (2) one set for repair of the SRU. This explains why two rows of SE data are entered for each failure mode.

Where the failure mode has no associated SRU, then a chassis or carcass failure has occurred. The SE to repair the carcass is then given in the body of the table.

THIS AREA FOR RUN ID

FIGURE 9

WEAPON SYSTEM FACTORS

NO. BASES	47
PERCENT BASES OS	20.0
YR SYSTEM LIFE	10.
EQUIV WEAPON SYST/BASE	1.
SYSTEM OPERATING HR/MO	120.
SYS SE DEVELOP COST	1000000.

SENSITIVITY ANALYSIS DATA

OPTION	4
LOW RATIO	0.50
HIGH RATIO	2.00
EXTRS. OR ALL	1

WHOLESALE CHANGE FACTORS

COST = 1.00
MTBF = 1.00
SE = 1.00

MAINTENANCE SYSTEM FACTORS

AVAIL WORKTIME/MAN AT BASE (MH/MO)	132.
BASE LABOR RATE/MAN ($/HR)	16.42
AVAIL WORKTIME/MAN AT DEP (MH/MO)	136.
DEPOT LABOR RATE/MAN ($/HR)	34.85
ANN TURNOVER RATE BASE PERS	0.330
ANN TURNOVER RATE DEP PERS	0.150

SUPPLY SYSTEM FACTORS

INTRO COST/LINE ITEM ($/ITEM)	104.20
RECUR COST/LINE ITEM ($/ITEM/YR)	104.20
BASE SUPPLY MGT COST ($/ITEM/YR)	20.00
ORDER & SHIP TIME CONUS (MO)	0.270
ORDER & SHIP TIME OS (MO)	0.530
PACKAGING COST CONUS ($/LB)	0.43
PACKAGING COST OS ($/LB)	0.54
PACKED WT RATIO CONUS (PK/UNPK)	1.28
PACKED WT RATIO OS (PK/UNPK)	1.44
SHIPPING RATE CONUS ($/LB)	0.39
SHIPPING RATE OS ($/LB)	0.57
COST/ORIG PAGE TECH DATA ($/PAGE)	190.

FIGURE 10

SUPPORT EQUIPMENT INPUT VALUES

SE CODE	SE NAME	$ UNIT COST	OPER. COST PER YEAR	NO. EXIST SE/LOCATION	CURR USE HR/MO	AVAIL OPER HR/MO	$ COST NEW FACIL.
DEPOT							
2001	MULTIMETER	90.	1.80	1	3.	200.	0.
2002	OSCILLOSCOPE	2375.	47.50			200.	0.
2003	SIGNAL.GEN.	4750.	95.00			200.	1.
2004	PULSE.GEN.	1350.	27.00			200.	0.
2005	POWER.SUPPLY	600.	12.00			200.	0.
2006	UNIV.BRIDGE	1375.	27.50			200.	0.
BASE							
6001	MULTIMETER.*	90.	1.80	1	3.	200.	0.
6002	OSCILLOSCOP*	2375.	47.50			200.	0.
6003	SIGNAL.GEN.*	4750.	95.00			200.	0.
6004	PULSE.GEN..*	1350.	27.00			200.	0.
6005	POWER.SUPP.*	600.	12.00			200.	0.
6006	UNIV.BRIDGE*	1375.	27.50			200.	0.

TARGET CHANGE FACTORS: SE 2002 COST = 1.50, SE 6002 COST = 1.50 LRU [illegible] COST = 1.50, MTBF = [illegible]

FIGURE 11

SE TO LRU/SRU RELATIONSHIPS

LRU NAME / FAIL % / SRU NAME	IDENT NO / REP/MO / IDENT NO	DEPOT HR/MO	REP/MO / BASE HR/MO	1001	2002	2003	2004	2005	2006	5001	6002	6003	6004	6005	6006
1 ISOL REACTOR	LRU02		0.0 1												
100.0 2	0.0 3	0.3	0.0	X				X	X	X				X	X
2 DESPIKER BD	LRU03		0.1												
100.0	0.1	2.4	0.1	X	X	X		X		X	X	X		X	
3 VAR PW ENERG	LRU04		0.0												
100.0	0.0	0.8	0.0	X	X			X		X	X			X	
4 SUP ASSY	LRU05		0.0												
67.0	0.0	4 0.3	0.0	X						X					
CCA.CHEG SRU53		5 0.3	0.0	X	X	X		X		X	X	X		X	
33.0	0.0	0.3	0.0	X						X					
5 FAULT BD ASY	LRU06		0.0												
100.0	0.0	0.0	0.0	X	X	X		X		X	X	X		X	
6 ENGY REG BD	LRU07		0.0												
100.0	0.0	0.9	0.0	X	X	X		X		X	X	X		X	
7 TRG AMP BD	LRU08		0.0												
100.0	0.0	0.9	0.0	X	X	X	X	X		X	X	X	X	X	
8 SWTCH SCR AY	LRU09		0.0												
17.0	0.0	0.1	0.0	X	X	X		X		X	X	X		X	
DLAY.PCT SRU54		0.1	0.0	X	X	X		X		X	X	X		X	
17.0	0.0	0.2	0.0	X	X	X		X		X	X	X		X	
CS.TRANS SRU57		0.2	0.0	X						X					
33.0	0.0	0.4	0.0	X	X	X		X		X	X	X		X	
TTA.S.SC SRU60		0.4	0.0	X	X	X	X	X		X	X	X	X	X	
33.0	0.0	0.4	0.0	X	X	X		X		X	X	X		X	
9 STOR CAP MAD	LRU10		0.1												
100.0	0.0	0.3	0.0	X					X	X					X
10 PEN/SWT XFMR	LRU11		0.1												
71.0	0.0	0.9	0.0	X						X					
SWT.TENS SRU55		0.5	0.0	X						X					
25.0	0.0	0.2	0.0	X						X					
PLS.ENFT SRU56		0.2	0.0	X	X	X	X	X		X	X	X	X	X	
4.0	0.0	[illegible]	0.0	X						X					

A failure mode with no associated SRU could also be included to indicate the fraction of time that LRU retests okay (RTOK). In this case, the SE to test the LRU is given in the body of the table. The entries indicate the potential, not the actual assignment of LRUs and SRUs to SE.

3.5 <u>Computed SE Costs (Figure 12).</u> This is partly data from Input Record (4) and partly computations based upon Record (4). The first two columns indicate SE codes and SE names. Colums (3) and (4) give the number of existing and maximum potential new purchases. Columns (5) and (6) give usage hours per month. Column (7) gives the percent busy or usage rate. Column (8) gives the acquisition [illegible]. Column (9) gives the Life Cycle Operating Cost of the new and existing equipment. Column (10) give the cost of any facilities required for the equipment. [illegible], the sum of Columns (8), (9) and (10), gives the total life cycle system cost [illegible] per base basis. These costs would be incurred if a particular SE is used. Since [illegible] SE [illegible], totals are not meaningful and are not given.

3.6 <u>Support Equipment Requirements (Figure 13).</u> This display gives [illegible] of the NRLA solution related to SE. For depot and base, Columns [illegible] give SE code and name. Column (3) tells how many SE will be required. Columns (4), (5), and (6) report information from Columns (6), (7), and [illegible] of Figure 12.

Note the quantity of SE of a particular type required can only be the quantity listed in Figure 12 or none. If none are required the SE is not listed in Figure 13. If it is required the quantity shown in Figure 12 will be required in Figure 13. Thus, if Figure 12 shows 3 of a particular kind of SE, either 0 or 3 will be indicated by Figure 13. The use of <u>1</u> or <u>2</u> will not occur. This is due to the network algorithm. Column 4 gives the cost of purchasing the quantity. Column (5) shows the hours/month the SE will be in use and Column (6) shows the percentage of available time the SE will be in use.

3.7 <u>LRU and SRU Repair Level Decisions.</u> Figure 14 and its continuation, Figure 14a, give the repair level decisions plus related information. The output is in four groups of columns, (a) LRU/SRU name and identification number, (b) LRU life cycle cost per base for the repair option selected, (c) SRU life cycle cost per base for the repair option selected, and (d) cost of the LRU or SRU, failure rates, MTBF, MTBR, and life cycle demands <u>per intermediate location</u>. MTBR excludes effects of repair in place. It includes intermediate, depot, or scrap options only.

A cost entry indicates that the repair is made at the location indicated. The cost entered relates only to the LRU or SRU. It does not include SE costs which were shown in Figure 13. If an option has been deliberately excluded using the procedures of Input record 6 or 7, the word XCLD indicates the option excluded.

At the bottom of the figure totals for LRU and SRU decision costs are given by location selected (e), for the SE (f) from Output 5, Figure 13, for the SE development cost (g), and then (h) the optimal life cycle cost per base for the selected decision set.

These are the totals of the ten types of costs given in Table [illegible] for the items in the optimum solution. Notice that there are depot, scrap, and intermediate (B [illegible]) repair costs for LRU's and SRUs. There are costs for depot and intermediate SE. Decision Related Costs (DEC1 and DEC2) are included with the repair level decision costs. Thus, there are 8 entries in the summary table representing the 10 types of costs in the network. Only those costs are included which relate to the optimum solution.

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COMPUTED SE COSTS

Col 1 SE CODE	2 SE NAME	3 *** NO. *** CURR INV	4 NEW REQD	5 *** SE USE *** HRS/MO CURR	6 NEW	7 %USE	8 ACQ. $	9 10. YR OPER. $	10 FAC. $	11 TOTAL SE LC $/BASE
DEPOT										
1001	MULTIMETER	1	0	2.5	20.2	11.3	0.	18.	0.	0.
2002	OSCILLOSCOPE	0	1	0.0	10.1	5.1	3563.	475.	0.	86.
2003	SIGNAL.GEN.	0	1	0.0	9.1	4.5	4750.	950.	0.	121.
2004	PULSE.GEN.	0	1	0.0	2.1	1.1	1350.	270.	0.	34.
2005	POWER.SUPPLY	0	1	0.0	14.4	7.2	600.	120.	0.	15.
2006	UNIV.BRIDGE	0	1	0.0	0.6	0.3	1375.	275.	0.	35.
BASE										
5001	MULTIMETER.*	1	0	2.5	3.4	1.5	0.	18.	0.	18.
6002	OSCILLOSCOP*	0	1	0.0	0.2	0.1	3563.	475.	0.	4038.
6003	SIGNAL.GEN.*	0	1	0.0	0.2	0.1	4750.	950.	0.	5700.
6004	PULSE.GEN..*	0	1	0.0	0.0	0.0	1350.	270.	0.	1620.
6005	POWER.SUPP.*	0	1	0.0	0.3	0.2	600.	120.	0.	720.
6006	UNIV.BRIDGE*	0	1	0.0	0.0	0.0	1375.	275.	0.	1550.

FIGURE 12

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NETWORK RIA RESULTS

WHOLESALE CHANGE FACTORS
COST = 1.00
MTBF = 1.00
SE = 1.00

SUPPORT EQUIPMENT REQUIREMENTS

Col 1 SE CODE	2 NAME	3 REQMT	4 TOTAL SE LC $/BASE	5 USE HRS	6 USE %
DEPOT					
1001	MULTIMETER	0	0.	20.	11.3
2002	OSCILLOSCOPE	1	86.	10.	5.1
2003	SIGNAL.GEN.	1	121.	9.	4.5
2004	PULSE.GEN.	1	34.	2.	1.1
2005	POWER.SUPPLY	1	15.	14.	7.2
2006	UNIV.BRIDGE	1	35.	1.	0.3
TOTAL			291.		

BASE SE CODE	NAME	REQMT	TOTAL SE LC $/BASE	USE HRS	USE %
5001	MULTIMETER.*	0	18.	0.	1.5
6002	OSCILLOSCOP*	1	4038.	0.	0.1
6003	SIGNAL.GEN.*	1	5700.	0.	0.1
6005	POWER.SUPP.*	1	720.	0.	0.2
TOTAL			10476.		

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LRU & SRU REPAIR LEVEL DECISIONS

	(3) LRU/SRU NAME	IDENT NO	(5) -- LRU (LC $/BASE) -- DEPOT	SCRAP	BASE	-- SRU (LC $/BASE) -- DEPOT	SCRAP	BASE	LRU/SRU COST	LRU FAIL %	INPUT MTBF	MTB REPAIR	LC REP DEM/BASE
1	ISOL REACTOR	LRU02	XOLD	2337.					1250.	100.0	25000.	27778.	2.1
2	DESPIKER BD	LRU03			4965.				1394.	100.0	3000.	3333.	17.3
3	VAR PW EMERG	LRU04	4476.		XOLD				5166.	100.0	3500.	3889.	3.7
4	SCP ASSY	LRU05							4552.		5000.	5556.	2.6
	...CHRG	SRU55	789.			465.			696.	67.0		8292.	1.7
			1011.							33.0		16835.	0.9
5	FAULT BD ASY	LRU06		110.					1770.	100.0	300000.	333333.	0.0
6	... BD	LRU07	2095.						2306.	100.0	3500.	3889.	3.7
7	... AMP BD	LRU08	1444.	XOLD	XOLD				1524.	100.0	3500.	3889.	3.7
8	SWITCH ... AY	LRU09			1207.	XOLD	XOLD	809.	17670.		2500.	2778.	5.2
	...LAY.SCT	...	1120.			XOLD	779.		674.	17.0		15340.	0.9
	...	SRU57	2128.			104.			644.	17.0		15340.	0.9
	...	SRU60	5031.						1500.	33.0		8418.	1.7
										?.0		8418.	1.7
9	... PWR ...	LRU10	1959.						2333.	100.0	15000.	16667.	3.5

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LRU & SRU REPAIR LEVEL DECISIONS (CONT.)

	LRU/SRU NAME	IDENT NO	-- LRU (LC $/BASE) -- DEPOT	SCRAP	BASE	-- SRU (LC $/BASE) -- DEPOT	SCRAP	BASE	LRU/SRU COST	LRU FAIL %	INPUT MTBF	MTB REPAIR	LC REP DEM/BASE
21	... V PWR SUP	LRU25							15600.		4500.	3889.	3.7
	...D	SRU58	1035.			514.			1169.	33.0		11785.	1.2
	...LAY	SRU59			2351.	1119.			905.	62.0		6270.	2.3
			798.							5.0		77773.	0.2
22	... SWITC	LRU26	1320.						3555.	100.0	10000.	11111.	1.3
23	T... REACT	LRU27	552.						4000.	100.0	15000.	16667.	0.9

----------- LC $/BASE -----------

	DEPOT	SCRAP	BASE
TOTAL LRU COSTS	41001.	2547.	32795.
TOTAL SRU COSTS	6332.	479.	406.
TOTAL ... COSTS	231.		10476.
... MENT COST		81277.	

TOTAL COST OF REPAIR LEVEL DECISIONS = 119524.

WHOLESALE CHANGE FACTORS
COST = 1.00
MTBF = 1.00
... = 1.00

••••••••••••••••••••

There are seven possible decisions for each LRU/SRU failure mode pair. (See Table 14 in Appendix 1.) The seventh decision (LRU scrap and SRU depot) is an undesireable outcome. For technical reasons its possibility of occurrence can not be prevented. Its likelihood of occurrence however is very low. When it occurs, the message 'CASE 7 ERROR' will appear in the output under the SRU *Life Cycle Costs* columns. Appendix 4 gives additional detail. The user should then rerun the program in two variations for each occurrence: (1) excluding the LRU scrap option, and (2) excluding the SRU depot repair option. The minimum cost variation of the two runs should then be selected as the decision.

3.8 Repair Level Decision Details. Figure 15 contains five types of data for LRUs, (a) a listing of input record 5 plus life cycle demands and mean time between demands for the LRU, (b) failure mode input data for the LRU, plus MTBR and life cycle demands/base, (c) SRU input data values, (d) LRU logistic costs, and (e) SRU logistic costs. Items (a)-(e) are so marked in Figure 15.

As part of the input the user specifies any forced repair level exclusions. These are listed in sections b and c since they are part of the input data. A 'zero' entry indicates item was not excluded. A 'one' entry indicates forcible exclusion. Two 'ones' means that the third item has been forced in. If three 'ones' were erroneously entered these were changed to 'zeros' as part of the computation and a message printed following the Support Equipment Input Values, Figure 10. The run was continued with no exclusions for the item and all 'zeros' would be printed.

Sections (d) and (e) of this display give the ten logistic costs to be discussed in conjunction with Table 13 in Appendix 1. They are intended for informational use only. It is not possible to compare the totals and select the proper repair level, since Support Equipment costs and new repair facilities costs are not included.

No SE acquisition and maintenance costs are shown. Rather *** is printed. These SE costs are given in Output 5 (Figure 13). They are not shown with the LRUs or SRUs since no proration is performed. Finally, the optimal decision is given for the item. If a Case 7 error has occurred this message will be printed below the optimal decision statement. The # indicates that the cost occurs only if the LRU is base repaired.

3.9 Sensitivity Analysis. In order to understand the sensitivity output the user should understand the sequence of computations for sensitivity analysis. The base line case is computed for which the solution has already been given. The problem is then solved sequentially from the Lower Range (L) to the Upper Range (U) for the LRU or SRU parameter being investigated.

The value at which a change occurs is determined within 1% of the value of the LRU. Thus, two ranges must be displayed: (1) the range over which a given RLA decision holds, and (2) the 1% range of uncertainty in which the change of RLA decision occurs. The 1% pertains to LRUs only. The effect on SRUs may be far different than 1% of the SRU value.

3.10 Summary Results - These are printed as part of the Repair Level Decision Details following the respective failure mode details. In Figure 16 (a) two values appear vertically as the decision change point, the upper and lower limits of the 1% range. Vertically down the left column the LRU or SRU involved in the changes due to sensitivity analysis are given. The decision is shown between the change points indicating that the decision is good only over the range indicated by the change point.

FIGURE 15

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REPAIR LEVEL DECISION DETAILS

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LRU NAME SWTCH SCF AY [illegible] LENT LR-009

LRU/END-ITEM	1.	REPAIR CYCLE (MO)		% REPAIR-IN-PLACE	10.	MTB FAILURES	2[illegible]0.
COST ($/LRU)	[illegible]	DEPOT-CONUS	1.50	NO. KINDS OF SE [illegible]	[illegible]	MTB REPAIRS	[illegible]
WEIGHT (LB/LRU)	5.0	DEPOT-OS	1.50			LRU DEM/BASE	5.2
LRU [illegible]	[illegible]	BASE	0.[illegible]3				

FAILURE MODE # 1 (RLAY.RCT) EXPECTED % OF FAILURES 17.0% MTB REPAIRS 15340. LRU DEM/BASE 0.9

RLA OPTIONS (LC $/BASE)	DEPOT	INTER	SCRAP
[illegible] ACQ. & MAINT.	***	***	
[illegible] DATA ACQ.	4.	4.	
TRAINING	24.	108.	
REPAIR LABOR	12.	6.	
[illegible] ENTRY	24.	[illegible]4.	
SUPPLY ADMIN.		200.	
REPAIR MATERIAL	0.	0.	
PACKING & SHIPPING	9.	0.	4.
BASE SPARES LEVEL	[illegible]5.	554.	555.
DEPOT SPARES LEVEL	3[illegible].		
REPLACEMENT SPARES			15572.
TOTAL [illegible]	1117.	1[illegible].	15232.

INPUT DATA VALUES

NO. NEW PARTS & ASSYS/REPR	1	DEPOT MAINT MH/REPR	[illegible].40
NO. PTS-ASSYS NEW AT BASE	0	BASE MAINT MH/REPR	0.40
$ VALUE PARTS-ASSYS	0.0	WKS MAINT TRAINING	[illegible].05
LB PARTS ASSYS	0.10	TRAINING $/ PRS/WK	200.00
NO. DEPOT PERS TRAINED	6	NO. PAGES TECH DATA	1.00
NO. BASE PERS TRAINED	2	NO. KINDS SP SE REQD	0
SE HOURS PER REPAIR	0.40	EXCLUDE DEPOT	0
		EXCLUDE SCRAP	0
		EXCLUDE BASE	0

OPTIMAL DECISION INCLUDING SE IS -- BASE

DATA FOR [illegible] (RLAY.RCT [illegible] SF154)

RLA OPTIONS (LC $/BASE)	DEPOT	INTER	SCRAP
SE ACQ. & MAINT.	***	***	
TECH DATA ACQ.	12.	12.	
TRAINING	24.	308.	
REPAIR LABOR	12.	6.	
ITEM ENTRY	24.	24.	
SUPPLY ADMIN.		200.	
REPAIR MATERIAL	1[illegible]9.	178.	
PACKING & SHIPPING	4.#	0.	[illegible].#
BASE SPARES LEVEL	59.#	77.	[illegible].#
DEPOT SPARES LEVEL	130.#		
REPLACEMENT SPARES			594.
TOTAL (IF LRU DEPOT)	[illegible]1.		[illegible].
*TOTAL (IF LRU BASE)	443.	306.	5[illegible]4.

INPUT DATA VALUES

$ COST/SRU	674.00	MO. DEP REPR CYCLE CON	1.50
LB/SRU	2.00	MO. DEP REPR CYCLE OS	1.50
$ COST PIECE PARTS &		MO. BASE REPR CYCLE	0.33
ASSYS/SRU REPR	[illegible]02.00	DEPOT MAINT MH/REPR	0.40
LB PARTS & ASSYS	0.10	BASE MAINT MH/REPR	0.40
NO. NEW PARTS & ASSYS	1	NO. DEP PERS TRAINED	[illegible]
NO. PTS-ASSYS NEW AT BASE	0	NO. BASE PERS TRAINED	[illegible]
NO. PAGES TECH DATA	3.	WKS. MAINT TRAINING	[illegible].05
NO. KINDS SE REQD.	8	TRAINING $/PERS/WK	[illegible].00
SE HOURS PER REPAIR	0.40	EXCLUDE DEPOT	1
		EXCLUDE SCRAP	1
		EXCLUDE BASE	0

OPTIMAL DECISION INCLUDING SE IS -- BASE

FIGURE 16

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REPAIR LEVEL DECISION DETAILS

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LRU MTBF (2500.0) SENSITIVITY -- MTBF RANGE = 1250.0 TO 5000.0 (50.% TO 200.%)

		1250.0 1250.0	$\boxed{1445.3 \; 1454.8}$	1640.6 1660.2	2304.7 2324.2
LRU09	1	BASE	BASE	BASE	BASE
SRJ54		BASE	BASE	BASE	BASE
LRU09	2	* BASE	BASE	* DEPO	DEPO
SRJ57		* BASE	* SCRP	SCRP	SCRP
LRU09	3	DEPO	DEPO	DEPO	DEPO
SRU60		DEPO	DEPO	DEPO	DEPO
LRU09	4	* BASE	BASE	BASE	* DEPO
TOTAL NO. LRU/SRU CHGS		3	1	1	1
TOTAL NO. SE CHGS		0	0	0	0

FIGURE 17

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REPAIR LEVEL DECISION DETAILS

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LRU NAME- STOR CAP MAD IDENT LRU10

LRU/END-ITEM	4.	REPAIR CYCLE (MO)		% REPAIR IN PLACE	10.	MTB FAILURES	15000.
COST ($/LRU)	2338.	DEPOT-CONUS	1.50	NO.KINDS GP SE REQD	4	MTB REPAIRS	16667.
WEIGHT (LB/LRU)	0.5	DEPOT-OS	1.50			LC DEM/BASE	3.5
LRU HRS/END-ITEM HRS	1.00	BASE	0.33				

FAILURE MODE # 1 ( ) EXPECTED % OF FAILURES 100.0% MTB REPAIRS 16667. LC DEM/BASE 3.5

RLA OPTIONS (LC $/BASE)

	DEPOT	INTER	SCRAP
SE ACQ. & MAINT.	***	***	
TECH DATA ACQ.	20.	20.	
TRAINING	24.	308.	
REPAIR LABOR	29.	13.	
ITEM ENTRY	24.	24.	
SUPPLY ADMIN.		200.	
REPAIR MATERIAL	1213.	1213.	
PACKING & SHIPPING	4.	0.	2.
BASE SPARES LEVEL	422.	482.	612.
DEPOT SPARES LEVEL	224.		
REPLACEMENT SPARES			3090.
TOTAL (W/O SE COST)	1949.	2261.	8494.

INPUT DATA VALUES

NO. NEW PARTS & ASSYS/REPR	1	DEPOT MAINT MH/REPR	0.23
NO. PTS-ASSYS NEW AT BASE	0	BASE MAINT MH/REPR	0.23
$ VALUE PARTS-ASSYS	391.00	WKS MAINT TRAINING	0.06
LB PARTS-ASSYS	0.01	TRAINING $/PERS/WK	200.00
NO. DEPOT PERS TRAINED	6	NO. PAGES TECH DATA	5.00
NO. BASE PERS TRAINED	2	NO.KINDS SP SE REQD	0
SE HOURS PER REPAIR	0.23	EXCLUDE DEPOT	0
		EXCLUDE SCRAP	0
		EXCLUDE BASE	0

OPTIMAL DECISION INCLUDING SE IS -- DEPOT

LRU UNIT COST (2338.0) SENSITIVITY --COST RANGE = 1169.0 TO 4676.0 (50.% TO 200.%)

*** NO DECISION CHANGES ***

The multiple asterisks (b) over one set of decisions indicates the baseline case optimal decision. The asterisks related to the Lower (L) range (c) indicate the number of changes from the baseline case to the Lower end of the range. The single asterisks (d) in the body of the table indicate where the changes occur compared to the adjacent decisions.

Below a count of the changes is given. The count at the very left hand column (e) is the number of changes from the baseline case (multiple asterisks) to the lower limits. Succeeding counts moving to the right (f) are the number of changes from the preceding lower value decision. Note that only the details of the decision changes for LRUs and SRUs being investigated are given. This is due to space limitation. If the count of changes is greater than the number shown, the complete analysis at the end of the run should be consulted.

Where no changes occur over the entire range, the statement NO DECISION CHANGES is printed in lieu of a table (Figure 17).

The count of SE changes is given as part of Sensitivity Summary, but the listing of the SE changes is given with the complete sensitivity results Output 8, Figure 19.

As an example in Figure 16, LRU 9 is Depot repaired at the original solution when SRU 57 is the failure mode. When the MTBF is reduced 50% to 1250 hrs, the LRU is base repaired in the SRU 57 is failure mode. It remains base repaired as MTBF increases until MTBF = 1640. Between 1640 and 1660 the LRU changes to depot repair. This is the 1% range of uncertainty. Notice that SRU 57 changes from base to scrap in the 1445-1464 hour range.

After the initial problem has been optimized (indicated by ****), the lower bound solution is calculated, here the 1250 hours level. The number of RLA changes from optimum to the lower bound for LRU and SRU are indicated by the adjacent *. A count of the number of changes is made and the total (here 3) is indicated. Except for the first column, * at each column indicates the item changed from the preceding column. Below the count of the changes is given. See Figure 16 where SE change counts are shown.

3.11 Summary Statistics

Following the Repair Level Decision Details summary, statistics for the model are given. These are shown in Figure 18. They are printed just before the Detailed Sensitivity Analysis. They are self-explanatory except for SE Cross Reference Size. This is the number of Xs which appear in Figure 11. Alternatively this is the number of ways LRUs and SRUs relate to SE. The number of network arcs listed includes the relational or dummy arcs.

3.12 Detailed Sensitivity Analysis

The last NRLA output gives detailed sensitivity analysis. The LRUs are numbered *sequentially (Figure 19). For SRUs both LRUs and SRUs are numbered (see Figure 19).* The alphabetic listing below has matching alphabetic identification in Figures 19 and 19a.

FIGURE 18

```
ARRAY SIZE REQUIREMENTS
    NO. OF SE   12     NO. OF LRU'S   23     NO. OF FAILURE MODES   33     NO. OF SRU'S   10

    SE CROSS REF SIZE  190     NO. NETWORK NODES  100     NO. NETWORK ARCS  361
*********************
  1 IDCI TRACTOR    LRU02    (MTBF BASE =    25000.) (1)    FIGURE 19
                                                  FROM                      TO
                          OVERALL MTBF RANGE    =    12500.0 ( 50.0%)    50000.0 (200.0%) (1)
                               THIS MTBF RANGE  =   25000.0 (100.0%)    12500.0 ( 50.0%)
              (c) SE COST CHANGES  (LC $/BASE)      10767                12417
        (1)   ADD UNIV.BRIDGE*(6005) ($     1350)
                           IDENT      FAIL %                                            SRU NAME   IDENT     FROM     TO
                           LRU02      100.             SCRP                 BASE
                  TOTAL COST (LC $/BASE)         =    96368
                               THIS MTBF RANGE  =   22851.6 ( 91.4%)    23046.9 ( 92.2%)
                  SE COST CHANGES  (LC $/BASE)      12417                10767
              DEL UNIV.BRIDGE*(6005) ($     1350)
                           IDENT      FAIL %                                            SRU NAME   IDENT     FROM     TO
                           LRU02      100.             BASE                 SCRP
                  TOTAL COST (LC $/BASE)         =    95933                95911
                               THIS MTBF RANGE  =   23046.9 ( 92.2%)    50000.0 (200.0%)
                  TOTAL COST (LC $/BASE)         =    95911                94293
                                            NO DECISION CHANGES
-----------------------------------------------------------------------------------------------------------
                                                  FIGURE 19A
  7 TRS AMP 50      LRU06    (MTBF BASE =     3500.)
                                                  FROM                      TO
                          OVERALL MTBF RANGE    =    1750.0 ( 50.0%)     7000.0 (200.0%)
                               THIS MTBF RANGE  =    3500.0 (100.0%)     1750.0 ( 50.0%)
                                                  NO DECISION CHANGES
                  TOTAL COST (LC $/BASE)         =    96845
                               THIS MTBF RANGE  =    1750.0 ( 50.0%)     7000.0 (200.0%)
                  TOTAL COST (LC $/BASE)         =    96845                95963
                                                  NO DECISION CHANGES (1)
*********************
  8 SWTCH SCR AY    LRU03    (MTBF BASE =     2500.)
                                                  FROM                      TO
                          OVERALL MTBF RANGE    =    1250.0 ( 50.0%)     5000.0 (200.0%)
                               THIS MTBF RANGE  =    2500.0 (100.0%)     1250.0 ( 50.0%)                 (1)
                           IDENT      FAIL %                                            SRU NAME   IDENT     FROM     TO
                           LRU09      17.              DEPO                 BASE        SW.TRANS   SRU07     SCRP     BASE
                           LRU09      13.              DEPO                 BASE
                  TOTAL COST (LC $/BASE)         =   103491
                               THIS MTBF RANGE  =    1445.3 ( 57.8%)     1464.8 ( 58.6%)
                           IDENT      FAIL %                                            SRU NAME   IDENT     FROM     TO
                           LRU09      17.                                               S.TRANS    SRU57     BASE     SCRP
                  TOTAL COST (LC $/BASE)         =   101544               101371
                               THIS MTBF RANGE  =    1640.6 ( 65.6%)     1660.2 ( 66.4%)
                           IDENT      FAIL %                                            SRU NAME   IDENT     FROM     TO
                           LRU09      17.              BASE                 SCRP
                  TOTAL COST (LC $/BASE)         =    99975                99834
```

(a) The identification of the LRU/SRU, type of sensitivity (cost or MTBF) and the baseline level are given (Figure 19).

(b) <u>Overall (MTBF or Cost) Range</u>. <u>This (MTBF or Cost) Range</u>. The first range listed represents the change from the base to the lower limits with the FROM containing the base value and the TO containing the lower limit. In succeeding cases the lower limit represents the level at which the FROM decision holds and the upper limit at which the TO decision holds. The 1% (or less) range between the lower and upper limit represents the level of accuracy.

(c) If SE changes occur the total value of all SE used at the FROM and TO levels is given (see Figure 19).

(d) If SE changes occur, these are listed along with the SE codes and cost of the SE involved. The Adds and Deletes represent the change in equipment which occurs between the FROM and TO range.

(e) The next output is listed in two groups, LRUs at the left and SRUs at the right. The SRUs are listed adjacent to the related LRU failure modes. The LRU identifier is given, its failure percent and the decision change. Only items which change are listed. The total RLA life cycle costs/base are given.

(f) If no decision changes take place over a range a message stating NO DECISION CHANGES is printed. This message can only occur between the baseline and lower limits or between the upper limits and some value less than the upper limit.

If it is desired to know the total SE or LRU/SRU status at some level, it would be necessary to trace all changes from the baseline case. As an extreme example, an SE might be added in going from base to lower limit and then deleted and added several times as the cost or MTBF increased. These changes coupled with other changes in SE would have to be traced if a total SE status were desired. An alternative would be to make another computer run at the level of cost or MTBF that the status was desired.

4. Execution Requirements and Error Messages

4.1 Execution Requirements. The NRLA Computer program was written in FORTRAN so that it can be adapted to different computer hardware and software configurations with minimal effort. This section presents information about data arrays in the program, so they can be adjusted for individual applications. It also presents information about data files used by the program.

The data array sizes specified when the program is compiled determine the amount of data that can be stored and used by the program. Therefore, for different applications with different amounts of support equipment and numbers of items, the array sizes may need modification. Any size changes required should be made in the main routine of the program and in all subroutines. Array size requirements are described as a function of the type of data stored in the arrays.

Support Equipment. All arrays in the labelled common areas SEIN and SECOMP should be dimensioned for the total number of support equipment resources to be considered by the program. The program variable MAXSE must be assigned a value equal to the size of the arrays so that it can be used to prevent array overflow.

LRUs. Arrays in the labelled common area LRUDAT are used to store LRU input data. Therefore, they must be dimensioned at least as large as the total number of different LRUs in the data file. The value assigned to the variable MAXLRU is used to prevent array overflow. Consequently, it should be set equal to the array dimension size.

LRU Failure Modes. Failure mode input values are stored in the arrays of the common area LFMDAT and computed values are stored in the arrays of the common area FMCOMP. All arrays in these areas should be dimensioned for the number of failure modes in the input data files. In addition, the arrays LDARC, LSARC, and LBARC in the common area ARCPTR should be dimensioned for failure mode data. The value of variable MAXLFM is used to prevent array overflow.

SRUs. Arrays to be dimensioned for SRU input values are in SRUDAT and the arrays for computed values are in SCOMP. The arrays SDARC, SSARC, SBARC, SBSARC, and SBDARC in the common area ARCPTR must also be dimensioned for storing SRU data. The variable used to prevent array overflow is MAXSRU.

SE Cross Reference. The arrays used to store SE to item relationships are contained in the labelled common area SEXDAT. The minimum size requirement for these arrays can be determined by summing for every LRU failure mode and for every SRU the number of SE resources utilized for item repairs. Two variables, MAXREF and MAXITM, are used to prevent array overflow.

Network Nodes. Data related to the network nodes is stored in the arrays of the common area NODDAT with the variable MAXNOD used to prevent array overflow. The size of these arrays can be computed as: (2 + No. SE + 2 (No. LRU failure modes) + 2 (No. SRUs)).

Network Arcs. Data related to the network arcs is stored in the arrays of the common area ARCDAT with the variable MAXARC used to prevent array overflow. These arrays should be as large as the number of arcs in the RLA Network. This size is computed as: No. SE resources + 3 (No. LRU failure modes) + 6 (No. SRUs) + (No. of SE to item relationship). This last factor is the same as the size requirement for SE Cross Reference arrays described above. Two of the arrays in ARCDAT, FLOW, and SAVFLO, are dimensioned for 2 values more than the other arrays.

Sensitivity Analysis. Data arrays used for sensitivity analysis information are contained in the labelled common area SENSIT. The arrays LOSTAT and HISTAT should be dimensioned the same as the arrays in NODDAT, LOCAP, HICAP, LOFLOW, and HIFLOW should be dimensioned the same as the arrays in ARCDAT. The first dimension of SADECL should match the size of the arrays in LFMDAT. The first dimension of SADECS should match the size of the arrays in SRUDAT.

As with any computer program, care must be exercised when changing the sizes of program arrays so that (1) sets of arrays which the program code assumes are all equal in size actually are, and (2) each array has the same dimensioned size in each subroutine.

The NRLA program uses eleven different data files during its execution. They are referenced as file codes 5, 6, 8, 10, and 13 through 19. The characteristics of these files are presented below so that the user can prepare appropriate file definition control cards.

File code 5 is used to input the wholesale change and Pareto change factors.

File codes 6 and 8 are used for program output print files. Each output record is written with a printer carriage control character and is no longer than 132 characters.

File code 10 is used for the input data file, as previously described.

File codes 13 and 14 are used during sensitivity analysis for temporary storage of network node and arc data. Each file is accessed as a random access file and contains only numeric information written as binary values. Each record on file 13 contains 3 values plus 1 value for each node of the network. The records on file 14 contain a value for each arc of the RLA network. Each file is used, essentially, as a "push-down stack" for data. The maximum depth required for the stack is dependent on the degree of decision sensitivity for the input file. It is unlikely to exceed 100 records per file.

File codes 15 and 16 also contain only numeric information written as binary values to random access files. File 15 contains one record, with 24 values, for each LRU failure mode. For each SRU a record of 26 values is written to file code 16.

File codes 17, 18, and 19 are used for temporary storage of sensitivity analysis results. The files are written and later read using sequential access I/O commands. Each record contains 11 numeric values written in binary format. Although the maximum file space required is dependent on the degree of decision sensitivity for the input file a rough estimate can be made. For files 17 and 19 the number of records written will normally be less than 4 (No. LRUs) + 2 (No. LRU failure Modes) . For file 18 the number of records written will normally be less than 4 times the number of SRUs plus 2 times the number of LRU failure modes.

One other execution related requirement exists for the NRLA program. A call is executed to a software supplied subroutine named DATE to obtain the current date as a six digit integer in the form YYMMDD. The subroutine name may have to be changed, as appropriate, or the CALL may have to be replaced with a READ instruction if the current date is not readily available to a FORTRAN program.

4.2 Error Message Explanations

1. VALUE OF OS $\leq$ 0 OR $\geq$ 100% _____TERMINATE

Percent of force OS is not feasible. It is less than 0% or greater than 100%. Program terminates.

2. INVALID ENTRY FOR SENSITIVITY_____VALUE SET TO 0.

Entry is 5 or greater. Only 0, 1, 2, 3, or 4 are valid entries.

3. INVALID ENTRY FOR SENSITIVITY LOWER BOUND VALUE__. SENSITIVITY TYPE SET TO 0.

The lower sensitivity bound has been entered as less than 0.0 or greater than 1.0. No sensitivity will be performed.

4. INVALID ENTRY FOR SENSITIVITY UPPER BOUND VALUE___. SENSITIVITY TYPE SET TO 0.

The upper sensitivity bound has been entered as less than .9999. No sensitivity will be performed.

5. INVALID ENTRY FOR SENSITIVITY QUANTITY. SENSITIVITY TYPE SET TO 0.

When determining whether "Extremes Only" or "Complete" sensitivity only 0 and 1 are valid entries.

6. OUT OF SPACE FOR___DATA

Record ___ ___ ___ ignored- Terminate.

Out of space for LRU, SRU, or SE Data. Redimension in order to run.

7. EXPECTING SE DATA OR 99 BUT FOUND ___. TERMINATE

Either invalid data was entered or a 99 separator card is missing after the SE Data.

8. SE DATA CARDS NOT IN ASCENDING ORDER.

Column 2 of SE Data entry record must be in ascending order.

9. EXPECTING LRU DATA CARD OR 99, BUT FOUND ___ ___ ___. TERMINATE

Either invalid data was entered or a 99 separator card is missing after the LRU Data.

10. IDENT_______________HAS RIP < 0 OR > 1.00

RIP = __________TERMINATE

The LRU identified has less than 0% or more than 100% repaired in place. Run terminated.

11. CANNOT FIND DATA FOR ___ ___ ___ ___. RUN TERMINATED.

SE resource cross reference, data card 8, contains LRUs, LRU failure modes or SRUs which are not listed in LRU, LRU failure mode or SRU data records.

12. 2 SE RECORDS GIVEN FOR__________.2d IS __________. TERMINATE

Duplicate SE cross reference card type 8 have been entered.

13. CANNOT FIND SE ___ FROM RECORD __________. TERMINATE

SE cross reference card calls for an SE not listed on SE data card.

14. OUT OF SPACE FOR SE CROSS REFERENCE __________. STOP AT __________. TERMINATE.

SE cross reference card not dimensioned large enough.

15. ____RECORD INDICATES ___ SE RESOURCES REQUIRED BUT ___ WERE ON THE SE DATA RECORD.

The count of SE required on the LRU data record does not match the count on the SE cross reference.

16. CANNOT FIND LRU BASIC DATA FOR ___. TERMINATE.

For an LRU failure mode no corresponding LRU was entered. For a card type 6 no corresponding card type 5 data was found.

17. LRU FAILURE MODE RECORD __________ OUT OF PLACE TERMINATE

All type 6 cards were not entered together. Run terminated.

18. TOTAL OF FAILURE PERCENTS $>$ 1.0 FOR ___. TERMINATE.

Failure percents for the failure modes of the LRU total to more than 100%.

19. IMPROPER SPECIFICATION OF DECISION OVERRIDE VALUES FOR ___. ALL THREE VALUES SET TO 0.

Input data excluded all repair level options. At most two of them may be excluded. All exclusions are deleted for this item and the run is continued.

20. NOT ENOUGH SPACE FOR SRU DATA __________. TERMINATE

Insufficient space was dimensioned for SRU data. Run terminates.

21. CANNOT FIND LRU FAILURE MODE FOR ___. TERMINATE

An SRU was listed with the SRU data for which there is no LRU failure mode data record. Card type 7 had no matching type 6 card.

22. INCONSISTENT LRU AND SRU DECISION OVERRIDE VALUES FOR ___. SRU VALUES SET TO 0.

The repair level exclusions are inconsistent. The SRU was forced to base while the LRU was forced out of base causing undesireable repair level selections. SRU exclusions are deleted and the run is continued.

23. SE DATA NOT FOUND FOR _____. TERMINATE

LRU data card 5 showed that SE is required but no type 8, SE cross reference card was found.

24. OUT OF SPACE FOR SE CROSS REFERENCE AT ____ ____. TERMINATE

SE cross reference arrays are dimensioned too small. Run terminated.

25. SE DATA NOT FOUND FOR _________. TERMINATE

LRU failure mode card 6 calls for SE but no corresponding type 8 card was found.

26. THE _________ IS NOT USED BY ANY LRU OR SRU.

The indicated SE is not used by any LRU, SRU, LRU failure mode.

27. _________ CANNOT FIND PROPER ARC _________ _________.

Probable program dimension error. See especially arrays FLOW and SAVFLO in subroutine MAXFLO. The arrys FLOW and SAVFLO must be dimensioned exactly 2 higher than the dimension of MAXARC. See also Program Array Dimensions, Appendix B of NRLA Programmer's Guide.

28. CASE 7 ERROR.

The model selected an inconsistent decision (LRU scrap and SRU depot). See also section 3.7, LRU and SRU Repair Level Decisions.

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5. User Questions and Answers

5.1 Introduction. The purpose of this paper is to provide the program user with information which will be helpful for conducting repair level analyses using the NRLA model. Some of the material expands and clarifies information from elsewhere in the NRLA User's Guide. Other material provides insight into how the model operates so that the user can fully understand and utilize its special features.

5.2 NRLA Output Report. As a first step in performing analysis with the NRLA model, the user should run the program with test data and ensure that the results are accurate. (Test data and a sample of output using the data are provided by AFALC/XRS with the computer program.) In the following, page numbers refer to the sample output and figure numbers refer to this guide.

The user should then jointly review the input data and output report to become familiar with where the input data is "echoed" for verification. In addition, the user should be certain he understands all of the output information so that items of interest can be easily and quickly located. The review of the output report may generate some questions. For example:

a. Pages 49 & 50 (Figures 14 and 15) show the "LRU & SRU Repair Level Decisions" and have columns labeled "Input MTBF" and "MTB Repair." Precisely what do these numbers represent?

A value appears in the Input MTBF column for each LRU and it is the MTBF value from the LRU Data Record. Immediately to the right is the MTB Repair value. It represents modifying the Input MTBF to account for organizational level (or on-equipment) maintenance. It is calculated by dividing the input MTBF by 1. minus the LRU's repair-in-place fraction. For an LRU with MTBF = 2500 hours and a repair-in-place fraction = 0.1, the MTB Repair would be 2778 hours (i.e., 2500/(1. - 0.1)). Below the MTB Repair value for the LRU are the corresponding MTB Repair values for each of its failure modes. These values are calculated by dividing the LRU's MTB Repair by each failure mode fraction (from the LRU's failure mode data records). For the above example, a failure mode which represents 33% of the off-equipment repairs has an effective MTB Repair of (2778/.33) = 8418 hours. If this particular failure mode has an SRU associated with it, the implication is that the LRU needs repair because of an SRU failure and that the SRU's MTB Repair is 8418 hours. Thus, the output report shows the SRU failure rates implied by the LRU MTBF and the failure mode fractions.

b. Starting on Page 50 (Figures 15d and e) is the section titled, "Repair Level Decision Details." It lists input values and the computed costs for each LRU failure mode and each SRU. Why does the cost element "SE ACQ. & MAINT." have "***" entered in both the depot and intermediate columns?

The cost for support equipment acquisition and maintenance is often critical for determining repair levels which minimize total cost. In NRLA these SE costs are computed but not prorated to individual LRUs and SRUs. Consequently, there is no specific fixed amount to be added with the other costs which are directly attributable to a failure mode or SRU. The "***" entry is included to remind the user that the SE costs are accounted for and do affect the optimal decisions. (The absence of the support equipment costs explains why the column total for a non-optimal decision may be lower than the column total for the optimal decision.)

c. The cost element "Item Entry" has values in the depot and intermediate columns but not in the scrap column. An LRU will have item entry costs even if it is discarded when it fails, so shouldn't there be an entry in the SCRAP column?

No. It is true that an LRU will have item entry costs regardless of which of the three repair level decisions is chosen. However, this cost is equal for all three choices and is ignored. The cost entries in the depot and intermediate columns represent the item entry costs for new piece-parts and assemblies required for LRU repair. Thus, they are item entry costs which are incurred if the LRU is repaired, at depot or intermediate level, but are not incurred if the LRU is discarded when it fails. Similarly, the "Item Entry" costs pertinent for the SRU repair level decisions are the item entry costs for the piece-parts and assemblies required for SRU repair. Item entry costs for the SRU itself are a "wash" across its three decisions. (The SRU's item entry cost is accounted for by counting the SRU as one of the new parts required for LRU failure mode repair.)

d. Page 50 (Figure 15e) shows input values and computed costs for an SRU. Why are some costs flagged with a '#'?

Certain SRU related costs are incurred if the associated LRU failure is repaired at intermediate level, but not if the LRU is repaired at depot level or is discarded. The SRU costs which are conditional on the LRU decision are flagged with a '#'.

Packing and Shipping costs are an example. If the optimal LRU decision is intermediate level repair, but the optimal SRU decision is depot repair, then the failed SRU must be shipped to the depot for repair and serviceable SRUs returned to base level supply. Similarly, if the LRU is repaired at intermediate level and the SRU is discarded, then replacement SRUs must be shipped from the depot. Conversely, if the LRU is repaired at depot level, then there will be no specific cost for shipping the SRU to the depot (the cost is part of the LRU packing and shipping cost) and there is no requirement to ship serviceable SRUs to base level supply.

The SRU "Base Spares Level" costs flagged with a '#' account for the serviceable spares in the depot to base order-and-shipping time pipeline. Thus, they are costs incurred if the LRU failure mode is repaired at base level by removing and replacing the failed SRU and that SRU is not repaired at base level (i.e., SRU depot repaired or discarded).

The "Depot Spares Level" cost for an SRU has a '#' because it accounts for the depot repair pipeline assets. As above, this pipeline of unserviceable SRU assets will only exist if the LRU is intermediate level repaired and the SRU is depot repaired.

As a final comment, when SRU related costs are listed there is an entry for "Packing and Shipping" and for "Base Spares Level" in the INTER column. These do not have the '#' because they are always incurred if the SRU is repaired at intermediate level (in this case the LRU decision will also be intermediate level repair). The packing and shipping cost accounts for the shipping of SRU repair parts from depot to base supply, and the base spares level accounts for unserviceable SRU assets in the base repair pipeline.

e. For each failure mode and SRU the logistics cost elements are added together. If this sum for a non-optimal decision choice is close to the sum for the optimal decision, does that mean that the non-optimal decision is almost as good a choice?

No. It must be remembered that the totals do not include support equipment costs and those costs can be very significant in determining the optimal choice. To determine the economic impact of the non-optimal decision, it would be necessary to rerun the program using the 'forcing' capability to exclude the other two decision choices.

5.3 NRLA Input Data File. Having obtained a good working knowledge of the program's input and output, the user should be ready to prepare his own data file.

The first three cards of data provide the program with weapon system utilization information, maintenance system factors, and support system factors. These data elements are generally obtained from, and/or approved by, the appropriate Air Force program office. (Maintenance system and supply system factors can be found in AFLC Pamphlet 173-10, "AFLC Cost and Planning Factors.")

5.3.1 The next group of input data records contain information about support equipment (SE) resources required for the repair of one or more LRUs and/or SRUs. Questions which could arise about these records include:

a. Since sophisticated, multipurpose support equipment may need to be portrayed as multiple resources (reference the SE discussion in Section 2.2 of the User's Guide), does that mean it is necessary to separately identify each and every support equipment item?

No, not necessarily. Sophisticated multipurpose support equipment should be portrayed as a basic unit plus additional hardware and/or software so that the basic unit and the 'add-ons' can be economically judged according to the capabilities they provide. A different situation exists in which support equipment items which are obviously separate and distinct can be lumped together for analytic convenience. Specifically, if a group of support equipment items (e.g., hand tools, or electronic devices, or some combination of things) is always used together then there is no compelling reason to identify the items individually. This situation is different than the prior one because the individual support equipment items can be viewed as providing repair capability only if all items in the group are purchased.

In addition to the convenience of grouping support equipment items, there is an implication for the program's execution time. This time is a direct function of the number of arcs in the RLA network. Therefore, some execution time reduction can occur because the grouping of SE items reduces the number of network arcs.

b. When developing the support equipment data records, how does the program recognize that an SE resource could be purchased for use at depot, or intermediate, or at both levels?

There is no specific "code" for this situation. It is necessary to have two SE data records, one for depot and one for intermediate. The program will then economically determine if one, both, or none should be purchased.

c. On the SE data record, the value for "Operating Cost/Year" is used to account for the operating and maintenance cost for electronic SE. Reprogramming of software for electronic SE is also a maintenance cost, how can it be included?

There are two ways. The same data value "Operating Cost/Year" can be used to account for anticipated reprogramming costs. The program uses the "Operating Cost/Year" to compute an annual maintenance cost and multiplies the cost by the number of years in the life cycle. Alternatively, the SE acquisition cost can be stated with the anticipated life cycle reprogramming cost already included and the operating cost ratio set to zero to avoid duplicate counting.

5.3.2 <u>NRTS Rate</u>. Following the SE data records the NRLA data file contains the LRU, LRU failure mode, and SRU data records. Uncertainties which could occur here include:

a. Why doesn't the LRU data record have a data field for the NRTS rate (Not Reparable This Station rate)?

There is no data field for NRTS, because it can be argued that at the time NRLA is run there is no NRTS rate - the purpose of NRLA is to use economic considerations to help determine the NRTS rate. This is done by considering the failure modes for the LRU and the costs for the repair alternatives.

For a minimum cost solution the model could determine that all failure modes for an LRU should be repaired at intermediate level. This implies a zero NRTS rate. Conversely, the model could recommend that all LRU failures should be repaired at depot, NRTS = 100%; or it could recommend a combination of intermediate and depot repair. In this latter case, the NRTS rate is determined by summing the Failure Mode Fraction input values for the failure modes assigned to depot level repair.

b. Since a NRTS rate is not specified, what should be done to indicate that some LRU repairs will be beyond the capability for maintenance at the intermediate level? Specifically, what can be done for failure modes for which some resource (e.g., skill type, skill level, facility, etc.) required for the repair is not available at intermediate level?

NRLA handles this situation by providing data fields on the failure mode records (and SRU records) which allow the user to forcibly exclude any one, or two, of the three decision alternatives. A '1' in the data field causes the program to ignore the computed cost for a decision alternative and replace it with an extremely large cost value. This large value assures that the alternative will not be part of the least cost solution.

At the same time, the other failure modes will be unrestricted for assignment of a repair level decision; however, that assignment may well be affected by the forced decision. This occurs because forcing a repair to depot (or to base level) implicitly forces the inclusion of support equipment required for the repair. Consequently, the support equipment becomes a "sunk cost" in terms of the economic evaluations for the other failure modes. This same reasoning explains how a forced decision for a failure mode can affect the decisions for SRUs in the LRU and/or can affect the decisions for other LRUs and their SRUs.

5.3.3 [illegible]

a. [illegible] an SRU which [illegible] discarded [illegible] be removed from the data file without any adverse effects?

In some cases yes, but [illegible]. If the SRU is discarded because repair is not feasible [illegible] SRU is very [illegible] then it [illegible] safely removed from the data file. In this case there is [illegible] advantage to removing the SRU because it will reduce the [illegible] work [illegible]. One consequence of removing the SRU which [illegible] data value in the associated LRU [illegible] mode record [illegible] "Repair Parts Cost" should be increased by the [illegible] cost of the SRU to reflect the fact that it is considered non-reparable.

The SRU [illegible] the data file if discard is an economic decision which [illegible] change. A [illegible] could occur as a result of revised estimates [illegible] SRU's cost, failure rate, repair time, or some other factor. Furthermore the decision could change because of changes to external factors; for example, a revised cost (lower) for support equipment, or higher costs for other SRUs which are discard and have common SE requirements. This latter condition results in the associated support equipment becoming more desirable, economically, because discard costs [illegible] increased.

[illegible] to the probability of a decision change away from discard can be obtained by reviewing the RLA [illegible] cost totals for an SRU. If the SCRAP option total is higher than the depot or the intermediate total, then discard was recommended because of the SE costs which are not shown (SE cost = "***"). In this case, changes in factors external to the SRU could cause its decision to change. The opposite situation, SCRAP option cost total lower than each of the others, implies that the discard decision will not be affected by external changes because discard would be recommended even if SE costs were zero. Thus, the SRU could be removed from the analysis as long as its data factors (cost, failure rate, etc.) do not appreciably change.

b. Since the SRU discard versus repair decision is unknown, what criteria are used to determine whether to include the SRU unit cost as part of the LRU failure mode repair parts cost, or not to include it?

The SRU cost should not be included if the SRU itself is included in the data file. When the SRU is present, the cost associated with its recommended repair decision will be appropriately included. Including the SRU unit cost as part of the repair parts cost implies that the SRU is non-reparable. This may distort the computations for the repair decision alternatives and produce erroneous and/or illogical results.

5.3.4 GPSE and SPSE. The LRU and LRU failure mode data records use the terminology General Purpose SE and Special Purpose SE. Exactly how are they different?

The difference is related more to the LRU itself than to the SE. In the SRLA terminology, an item of General Purpose SE could be a complex electronic LRU test set designed to handle a number of different LRUs, or it could be a peculiarly sized or shaped hand tool (e.g., wrench or screw driver) applicable to only one LRU. An SE item is considered to be General Purpose, in relation to a particular LRU, if it is used for LRU repair with each and every failure mode of the LRU. General Purpose simply means that the SE is used for each failure mode of a particular LRU. There is no implication or restriction on capability (a peculiar wrench or a sophisticated test set) or on applicability to other LRUs and/or SRUs.

The terminology Special Purpose SE is used to refer to SE items which are required for one or more failure modes of an LRU, but not required for each and every failure mode of the LRU. Once again, very diverse SE items - a peculiar wrench or a sophisticated test set - can be classified as Special Purpose and there is no implication about applicability to other LRUs and/or SRUs. Special Purpose is simply the term chosen to designate SE which is required by one or more, but not all, failure modes of an LRU.

Using this terminology, it is both easy and fully consistent for a specific SE item to be both General Purpose and Special Purpose. An SE item can be General Purpose with respect to one LRU if it is used for every failure mode of the LRU, and also be Special Purpose with respect to another LRU because it is not used for every failure mode of that LRU.

5.3.5 LRU/SRU/SE Relationships. The final set of data records in the NRLA file specify the item to SE relationships. To help clarify their usage:

a. There are 3 types of SE resource data records, the 32, 42, and 52. When is each one used?

The 3 types of cards are used in parallel with the LRU, LRU failure mode, and SRU data records. That is, a type 32 gives the General Purpose SE identifiers for a type 31 LRU data record, the 42 gives the Special Purpose SE identifiers for a type 41 failure mode data record, and a 52 gives the SE identifiers for a type 51 SRU data record. The type 32 record is intended to simplify data input because it can replace a set of type 42 records. For General Purpose SE, the program user could list an SE identifier on a type 42 record for each and every failure mode of an LRU, or it could be listed once on a type 32 record. The NRLA program uses the entries on a 32 record as applicable to each failure mode.

There is no program requirement to include all 3 types of data records in a data file. A file could have none, any one type, any two types, or all three types - the difference being a function of LRU and SRU support equipment requirements.

b. If intermediate level repair for an SRU will not be cost-effective, can the type 52 record specify only the depot level SE requirements and ignore the intermediate level SRU to SE relationship?

Probably not. By listing only depot support equipment the implication is that SE will be required if the repair is done at the depot, but SE will not be required if the repair is done at intermediate level. This will result in an illogical repair cost trade-off, depot repair with SE versus intermediate level repair without SE, and erroneously result in a recommendation for intermediate level repair.

5.4 NRLA Program Arrays. The final area covered here deals with the size of data arrays in the program.

a. What limitations does the program have for the number of LRUs, SRUs, and support equipment?

The NRLA program, as distributed by AFALC/XRS, has arrays sizes specified to hold data for up to [illegible] LRUs, [illegible] LRU failure modes, [illegible] SRUs, and [illegible] support equipment items.

b. What about other arrays of the program?

Other arrays hold data for the LRU and SRU versus SE relationships, the network nodes, and the network arcs. The default sizes for these arrays are: 210 for SE relationships, 200 for network nodes, and 400 for network arcs.

c. How can a user determine if the arrays are big enough for his data file?

For support equipment, LRUs, LRU failure modes, and SRUs simply count, or estimate, the number of input file data records of each type and compare to the sizes specified above.

For SE relationships, two types of computations must be performed and compared to the default size of 210. The first computation simply involves counting the number of SE identifiers on the type 32, 42, and 52 data records. The second computation is a two step process. The first step uses each type 32 record separately. The number of SE identifiers on each record is multiplied by the number of failure modes identified for the corresponding LRU. The second part is summing these products plus the number of SE identifiers on the type 42 and 52 data records.

The size requirements for node and arc arrays are determined by formulas. For node arrays the computation is:

2 + (No. of SE) + 2* (No. of LRU failure modes) + 2* (No. of SRUs)

and for network arcs it is:

(No. of SE) + 3* (No. of LRU failure modes) + 6* (No. of SRUs) + (No. of SE-to-item relationships)

The last term of this formula is the same as the second computation for SE relations, as described in the previous paragraph.

d. Should the default sizes be adequate, and what should be done if they aren't?

It is quite likely that at least some array sizes will have to be changed. The default sizes exist primarily because they were adequate and convenient for test data files used during program development. Recognizing that different NRLA applications would likely have very different array requirements, no attempt was made to determine "typical" array size requirements.

When array size changes are required, they should be done following the guidance in Appendix B of the NRLA Model Programmer's Guide. As is stressed, the redimensioning should not be difficult, but must be done carefully, accurately, and completely. The program logic makes certain assumptions about array sizes. For example, all arrays for LRU data are dimensioned to the same size; further, LRU arrays are the same size in every subroutine. If these assumptions are false, program aborts could occur or, even worse, computational errors could occur and remain undetected.

An additional point on redimensioning array sizes is that some temporary disk files used by the program may need to have their file definition parameters changed. This possibility is also discussed in Appendix B of the programmer's guide.

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Appendix 1

Logistic Costs Related to Network Costs

In order to operate the NRLA program, it is necessary to translate logistic costs into network costs. From the input data (see Chapter 2 for a complete list) eleven types of logistics costs are computed; ten types specifically related to LRUs and SRUs, and one specifically related to support equipment. These eleven are computed and summed, as appropriate, to determine ten types of cost elements used for constructing the repair level analysis network.

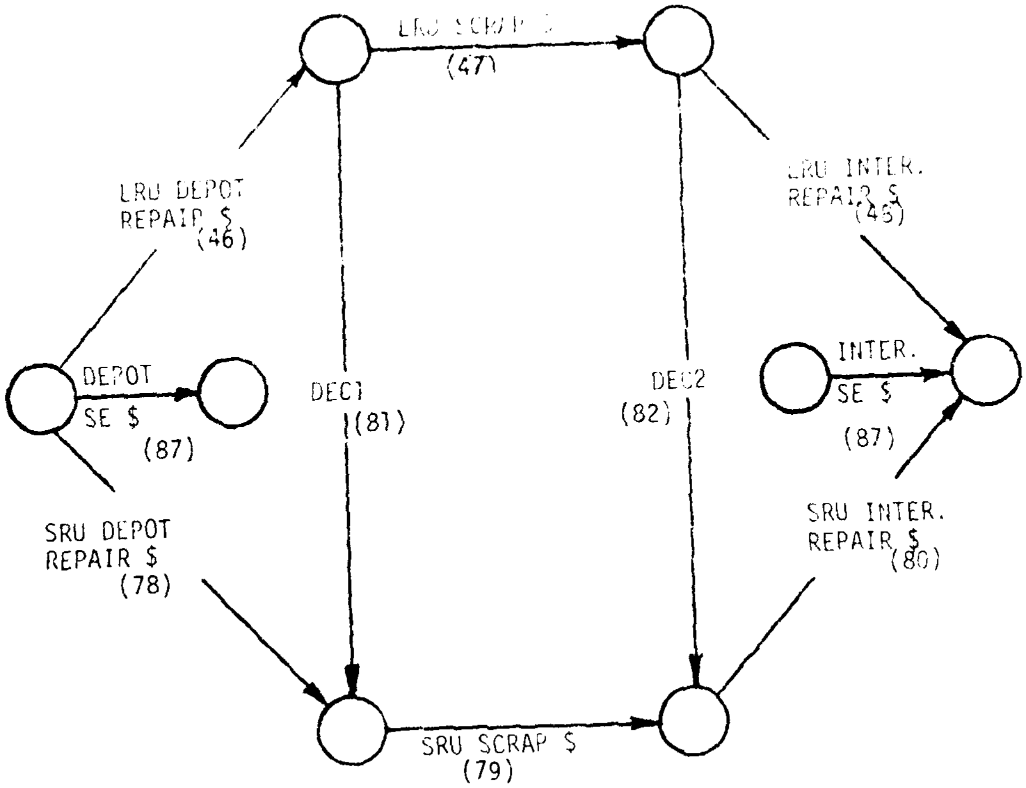
Table 13 lists the eleven types of logistics costs and shows how they relate to the ten network cost elements. The individual identifiers within a row of the table correlate with the equations in Appendix 3. They indicate which logistic costs are components of the respective network costs. A detailed description of the logistic cost equations is given in Appendix 3. As an example, the logistic cost for Maintenance Training at Depot for an LRU (C9D) is computed using the equations given in Appendix 3. This result, C9D, then becomes a component of the network related cost LRU Depot Repair (46). The network cost is applied to the network and is used in the max flow - min cut algorithm. Figure 20 shows the network costs associated with a sample network.

The computer program then uses the LRU - SRU - SE relationships at Depot and Intermediate to define an RLA network. The ten types of costs shown in Table 13 are then associated with the respective LRUs, SRUs, and SEs. The algorithm can select any of the seven decisions shown in Table 14. It selects the one that will yield the least cost set of repair level decisions based upon the associated costs. The same network is used for sensitivity analysis investigations by properly modifying costs.

TABLE 13. RELATIONSHIP BETWEEN LOGISTICS AND NETWORK COSTS

	Logistic Costs	Network (Decision Component) Costs									
		LRU			SRU					SE	
		Depot Repair	Scrap	Inter. Repair	Depot Repair	Scrap	Inter. Repair	Dec 1	Dec 2	Depot	Inter.
1	SE Acquis. & Maint.									SECOST	SECOST
2	Tech. Data Acquis.	C8D		C8B	C3D		C8B				
3	Maint. Training	C9D		C9B	C9D		C9B				
4	Repair Labor	C5D		C5B	C5D		C5B				
5	Item Entry	C6D		C6B	C6D		C6B				
6	Supply Admin.			C7B			C7B				
7	Repair Material	C1D		C1B	C1D		C1B				
8	Packing & Shipping	C2D	C2S	C2B			C2B	C2D1	C2D2		
9	Base Spares Quantity	C3D	C3S	C3B			C3B		C3D2		
10	Depot Spares Quantity	C4D						C4D1			
11	Replacement Spares		C1S			C1S					
	Totals	46	47	48	78	79	80	81	82	87	87

The logistic costs are in the sequence of the computer output Repair Level Decision Details (Fig. 18). The entries show which logistic costs are components of the network costs. The alphanumeric entry matches the equation names used in Chapter 3 making it possible for the user to cross reference the equations developed in Chapter 3 with the computer output. Totals entries are equation numbers from Chapter 3.



NOTE: DEC1 and DEC2 are SRU costs which are incurred if the LRU decision is intermediate level repair and (a.) the SRU decision is depot repair (DEC1), or (b.) the SRU decision is either depot repair or scrap (DEC2). Equation numbers are shown in parenthesis.

FIGURE 20. Basic Structure of an RLA Network.

TABLE 14 RLA DECISION COSTS

RLA DECISION COSTS						
	Decision		Included Costs			
			SE			
	LRU	SRU	DEP	INT	DEC 1	DEC 2
1	Depot	Depot	Yes	No	No	No
2	Inter	Inter	No	Yes	No	No
3	Scrap	Scrap	No	No	No	No
4	Depot	Scrap	Yes	No	No	No
5	Inter	Scrap	No	Yes	No	Yes
6	Inter	Depot	Yes	Yes	Yes	Yes
7*	Scrap	Depot	Yes	No	Yes	No

* This alternative cannot be eliminated for technical reasons however it is extremely unlikely to occur. Methods of handling it should it occur are given in Chapter 2.

Appendix 2

Glossary of Variables

This section is an alphabetical listing of the acronyms used in the equations of Appendix 3. With each acronym is its description, units of measures, and the source of the data value. The source will be one of the input data records or will indicate that the value is computed from input data values.

A	-	the expected annual cost for non-reparable assemblies and/or piece-parts required for repair of an LRU or SRU ($, Computed).
AVHRS	-	the expected number of hours per month that a particular type of currently installed support equipment will be available to support new workload of repair tasks (hours/month, computed).
BAA	-	available work time per shift per month for an intermediate level maintenance man (man-hours/shift/month, Maintenance System Data Record).
BLR	-	hourly labor rate for intermediate level maintenance man ($/hour, Maintenance System Data Record).
BMMH	-	the number of maintenance man-hours required for repair of an LRU if the repair is done at intermediate level (man-hours/repair, LRU Failure Mode Data Record).
BMMHS	-	the number of maintenance man-hours required for repair of an SRU if the repair is done at intermediate level (man-hours/repair, SRU Data Record).
BRCT	-	the total elapsed time from removal of a failed LRU at a base, through intermediate level repair, until it is returned to serviceable base stock (months, LRU Data Record).
BRCTPL	-	the expected number of unserviceable LRU assets in the base repair pipeline (No. LRU, Computed).
BRCTSL	-	the number of spare LRUs to be purchased to satisfy LRU demands expected to occur during the base repair cycle time (No. LRUs, Computed).
BSYHRS	-	average monthly in-use time for a particular type of currently installed support equipment (hours/month/unit of SE, Support Equipment Data Record).
DAA	-	available work time per shift per month for a depot level maintenance man (man-hours/shift/month, Maintenance System Data Record).
DEV	-	the cost to develop SE for the system ($1000, Weapon System Data Record).
DLR	-	hourly labor rate for depot level maintenance men ($/hour, Maintenance System Data Record).

DMMH - the number of maintenance man-hours required for repair of an LRU if the repair is done at the depot (man-hours/repair, LRU Failure Mode Data Record).

DMMHS - the number of maintenance man-hours required for repair of an SRU if the repair is done at the depot (man-hours/repair, SRU Data Record).

DRCTC - the elapsed time from removal of a failed LRU at a CONUS base until the item could become a serviceable spare in depot stock; it includes the time required for base to depot transportation and the depot shop flow time required for repair (months, LRU Data Record).

DRCTO - the elapsed time from removal of a failed LRU at an overseas base until the item could become a serviceable spare in depot stock (months, LRU Data Record).

DRCTPL - the expected number of unserviceable LRU assets in the depot repair pipeline (No. LRU, Computed).

DRCTSL - the number of spare LRUs to be purchased to satisfy LRU demands expected to occur during the depot repair cycle time (No. LRUs, Computed).

EOQ - the dollar value of the base level inventory of non-reparable assemblies and/or piece-parts required for LRU or SRU repair ($, Computed).

FAILP(i) - the LRU failure mode percentage, the expected frequency of the i^{th} type of failure as a fraction of all failures for the LRU (dimensionless, LRU Failure Mode Data Record).

IMC - initial management cost to introduce a new item (assembly or piece-part) into the Air Force wholesale level inventory system ($/item, Supply System Data Record).

M - the total number of operational locations for the end-item (No. bases, Weapon System Data).

MENREQ - the minimum number of trained maintenance men required to accomplish the expected monthly workload of LRU or SRU repairs (No. men, Computed).

MTBCT - mean end-item operating time between corrective repair tasks (operating hours, Computed).

MTBF - mean time between failures for an LRU in its operational environment (LRU operating hours/failure LRU Data Record).

NAB - the number of standard (already stock numbered in AF inventory) items which will have to be entered into the base inventory system if LRU repair is done at the base (No. items, LRU Failure Mode Data Record).

NABS - the number of standard (already stock [illegible] items which will have to be entered [illegible] SRU repair is done at the base (No. items, SRU D[illegible]).

NP[illegible] - th[illegible] number of new (not [illegible] assemblies required for [illegible] repair (N[illegible] Data Record).

NPPAS - the [illegible] of new [illegible] parts and/or assemblies required for SRU repair (No. [illegible], SRU Data Re[illegible]).

NSE - the number of [illegible] particular [illegible] of support equipment (No. SE, SE Data Record).

NTDFM - the number of technical data pages required to perform [illegible] LRU repair task (No. pages, LRU Failure Mode Data Record).

NTDS - the number of technical data pages required for SRU repair (No. pages, SRU Data Record).

OPHRS - expected time that a unit of SE will be available for item repairs (hours/month, SE Data Record).

OS - the fraction of the total number of end-items deployed to overseas locations (dimensionless, Weapon System Data Record).

OSTC - order and shipping time for CONUS locations; the elapsed time between the initiation of a request for a serviceable item from the depot and the receipt of the item at a CONUS base (months, Supply System Data Record).

OSTO - order and shipping time for overseas locations (months, Supply System Data Record).

OSTPL - the expected number of serviceable LRU assets in the depot to base order and shipping time pipeline (No. LRUs, Computed).

OSTSL - the number of spare LRUs to be purchased to satisfy LRU demands expected to occur during an order and shipping time cycle (No. LRUs, Computed).

PCC - packaging cost, including both labor and materials, for item shipments to CONUS bases ($/pound, Supply System Data).

PCO - packaging cost, including both labor and materials, for item shipments to overseas bases ($/pound, Supply System Data).

PGMB - monthly end-item utilization hours at a base (hours/intr location, Computed).

PGMLCB - life cycle end-item utilization hours at a base (hours/intr location, Computed).

PIUP - program inventory usage period; the life cycle of the system (years, Weapon System Data Record).

PSRC - packaging and shipping cost for CONUS shipments ($/pound, Computed).

PSRO - packaging and shipping cost for overseas shipments ($/pound, Computed).

PWRC - packed weight ratio for CONUS shipments; the ratio of the packaged item weight to the item weight (dimensionless, Supply System Data Record).

PWRO - packed weight ratio for overseas shipments (dimensionless, Supply System Data Record).

QTY - for each LRU, the number of occurrences of the LRU in the end-item (No. LRU/end-item, LRU Data Record).

REQMT - the number of units of a support equipment that will have to be purchased to satisfy the repair requirements (No. SE, Computed).

RIIMC - the life cycle recurring plus initial item management cost ($/item/intermediate location, Computed).

RIP - repair-in-place fraction; fraction of LRU failures which can be repaired at the organizational level, on-equipment maintenance (dimensionless, LRU Data Record).

RMC - recurring management cost to maintain an item in the wholesale inventory system ($/item/year, Supply System Data Record).

SA - annual cost to maintain an item in the base level supply system ($/item/year, Supply System Data Record).

SBRCT - SRU base repair cycle time; the total elapsed time from removal of a failed SRU from an LRU, through intermediate level repair, until it is returned to serviceable base stock (months, SRU Data Record).

SBRCTL - the number of spare SRUs to be purchased to satisfy SRU demands expected to occur during the SRU base repair cycle time (No. SRU, Computed).

SBRCTP - the expected number of unserviceable SRU assets in the base repair pipeline (No. SRU, Computed).

SDRCTC - SRU depot repair cycle time for CONUS bases; the elapsed time from removal of a failed SRU (from the LRU) at a CONUS base until the item could become a serviceable spare in depot stock (months, SRU Data Record).

SDRCTL - the number of spare SRUs to be purchased to satisfy SRU demands expected to occur during the SRU depot repair cycle time (No. SRUs, Computed).

SDRCTO - SRU depot repair cycle time for overseas bases; the elapsed time from removal of a failed SRU from the LRU at an overseas base until the item could become a serviceable spare in depot stock (months, SRU Data Record).

SDRCTP - the expected number of unserviceable SRU assets in the depot repair pipeline (No. SRUs, Computed).

SEACQ - support equipment acquisition cost for a particular type of SE ($, Computed).

SECOST - the total facilities, acquisition, and operations cost for a particular type of SE ($, Computed).

SEFAC - cost of new facilities for support equipment ($, Support Equipment Data Record).

SEHRFM - the number of hours the SE is needed to repair the LRU failure mode (hours/repair, LRU Failure Mode Data Record).

SEHRS - the number of hours the SE is needed to repair the SRU (hours/repair, SRU Data Record).

SEOPF - the annual cost of operations and maintenance for a support equipment ($/year, Support Equipment Data Record).

SEOPNS - life cycle operations and maintenance cost for a support equipment ($, Computed).

SOSTPL - the expected number of serviceable SRU assets in the depot to base order and shipping time pipeline (No. SRU, Computed).

SOSTSL - the number of spare SRUs to be purchased to satisfy SRU demands expected to occur during an order and shipping time cycle (No. SRUs, Computed).

SRC - cost for shipping items to CONUS locations ($/pound, Supply System Data Record).

SRO - cost for shipping items to overseas locations ($/pound, Supply System Data Record).

SWDRCT - SRU weighted depot repair cycle time (months, Computed).

TD - cost per original page of technical data produced by the contractor to support item repairs ($/page, Supply System Data Record).

TFB - training factor for base; the expected number of times that formal maintenance training will be required for base personnel (dimensionless, Computed).

TFD - training factor for depot; the expected number of times the [illegible] maintenance training will be required for depot personnel [illegible] less, Computed).

TLCD - total life cycle repair demands for an LRU at each base (No. repair demands,/L.C., Computed).

TLCDF - total life cycle repair demands for [illegible] failure mode of an LRU at each base (No. repair demands,/L.C., Computed).

TQCTGM - total questionable corrective tasks generated monthly at [illegible] base (No. repair/month, Computed).

TRB - annual turnover rate for intermediate level maintenance personnel (fraction of personnel replaced/year, Maintenance System Data Record).

TRC - the expected training cost, instruction and materials, for LRU repairs ($/man/week, LRU Failure Mode Data Record).

TRCS - the expected training cost, instruction and materials, for SRU repairs ($/man/week, SRU Data Record).

TRD - annual turnover rate for depot level maintenance personnel (fraction of personnel replaced/year, Maintenance System Data Record).

TRW - amount of training time required for LRU repair (weeks, LRU Failure Mode Data Record).

TRWS - amount of training time required for SRU repairs (weeks, SRU Data Record).

UCPPFM - total cost of all non-reparable assemblies and/or piece-parts required for repair of an LRU failure mode ($, LRU Failure Mode Data Record).

UCPPS - total cost of all non-reparable assemblies and/or piece-parts required for repair of an SRU ($, SRU Data Record).

UCS - unit cost of an SRU ($/SRU SRU Data Record).

UCSE - unit cost of a support equipment ($, Support Equipment Data Record).

UEBASE - the number of end-items operating at each base (dimensionless, Weapon System Data Record).

UF - LRU utilization factor; ratio of LRU operating hours to end-item operating hours (dimensionless, LRU Data Record).

UR - end-item utilization rate (operating hours/month, Weapon System Data Record).

USEHRS - for each SE the total [illegible] required [illegible] LRUs and SRUs [illegible].

WDRCT - weighted average of CONUS and overseas depot repair cycle times for an LRU (months, Computed).

WGTL - weight of an LRU (pounds, LRU Data Record).

WGTS - weight of an SRU (pounds, SRU Data Record).

WOST - weighted average of CONUS and overseas order and shipping times (months, Computed).

WPSR - weighted average of CONUS and overseas packing and shipping rates ($/pound, Computed).

WTPPFM - weight of non-reparable assemblies and/or piece-parts required of LRU repair (pounds, LRU Failure Mode Data Record).

WTPPS - weight of non-reparable assemblies and/or piece-parts required for SRU repair (pounds, SRU Data Record).

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Appendix 3

NRLA Cost Equations

1.0 Introduction. The Network RLA program is composed of two major parts. The first reads the input data and computes the costs associated with the repair level decision network. The second solves the repair level decision problem using a max-flow, min-cut algorithm and performs sensitivity analyses on the optimal solution. This chapter presents the rationale and equations for the first part of the program.

It is important for the analyst using the program to understand the cost equations used. Then the program can be modified, if necessary, to more accurately portray the costs associated with each specific application.

In general, the program computes two types of costs: item (LRU and SRU) related and support equipment (SE) related. Item related costs are further classified into the costs that occur if the item is:

a. depot repaired when it fails,

b. scrapped (discarded) when it fails, or

c. base repaired when it fails.

The different logistics costs computed for each repair level decision are shown in Table 13 (see Appendix 1).

The equation descriptions involve numerous acronyms for input data elements and computed values. Each acronym is defined at its first usage and a glossary is provided as Appendix 2.

2.0 Computations.

2.1 Logistics System Computations. In order to compute the item and SE related costs some general information is required. This information is contained in the weapon system, maintenance system, and supply system data records.

From the weapon system factors the monthly end-item utilization at a base (PGMB) is computed as:

1. PGMB = UEBASE * UR
(syst/base) * (hr/syst/ mo)
where UEBASE = the number of end-items at each base, and
UR = the utilization rate of each end-item in operating hours per month

The corresponding life cycle utilization at each base (PGMLCB) is computed by:

2. PGMLCB = PIUP * 12. * PGMB
(yr/L.C.) (mo/yr)(oper hr/base/mo)
where PIUP = program inventory usage period (the life cycle of the system in years)

From the maintenance system data record the annual turnover rate for depot maintenance personnel (TRD) is used to compute the expected number of times that formal maintenance training will be required. Assuming that training is required at the beginning of the system's life cycle, but none is required during the last year of the system's life, the training factor for depot personnel (TFD) is:

3. TFD* = 1. + TRD * (PIUP - 1)
 = 1 + (turnover/yr) * ((yr/L.C.)- 1)

The corresponding training factor for base level training (TFB) is:

4. TFB* = 1. + TRB * (PIUP - 1)
 = 1 + (turnover/yr)((yr/L.C.)- 1)
 where TRB = the annual turnover rate for base personnel
 Note: TFB and TFD are both rounded down.

The supply system factors are first used to compute a life cycle cost factor for new items entering the Air Force wholesale level inventory system. The life cycle recurring plus initial item management cost (RIIMC) is computed as a cost per base as:

5. RIIMC = (PIUP * RMC + IMC)/M
 ((yr/L.C.) * ($/yr) + ($/part intro))/(No. bases)

 where RMC = the annual item management cost,
 IMC = the initial cost for introducing an item into the wholesale level inventory system, and
 M = the number of operating bases.

The second factor computed from the supply system data is a weighted order and shipping time (WOST) for item requisitions:

6. WOST = OS * OSTO + (1. - OS) * OSTC
 (ratio OS ship)(mo OS ship) + (ratio CONUS ship) * (mo CONUS ship)

 where OS = the overseas deployment fraction,
 OSTO = the order and shipping time to overseas locations, and
 OSTC = the order and shipping time to CONUS locations.

Next, a packing and shipping rate for CONUS (PSRC) and overseas (PSRO) locations is computed:

7. PSRC = PCC + PWRC * SRC
 ($/lb packing CON) + ratio ($/lb ship)

 where PCC = the CONUS packing cost for labor and materials,
 PWRC = the packed to unpacked weight ratio for CONUS shipments, and
 SRC = the shipping rate, dollars per pound, to CONUS locations.

8. PSRO = PCO + PWRO * SRO
($/lb packing OS) + (ratio)($/lb ship)

where PCO = the overseas packing cost,
PWRO = the packed to unpacked weight ratio for overseas shipments, and
SRO = The shipping rate to overseas locations.

Finally, the weighted packing and shipping rate (WPSR) is computed:

9. WPSR = (1. - OS) * PSRC + OS * PSRO
= (ratio CON) * ($/lb pack & ship) + (ratio) * ($/lb pack & ship)

2.1 LRU Computations. LRU repair decision costs are computed using factors from the LRU data record and from the LRU failure mode data record.

Factors from the LRU data record are used to compute quantities which are required for the individual failure mode cost computations. For each LRU the following seven values are computed:

a. Mean time between corrective tasks (MTBCT),

10. MTBCT = MTBF/(UF * (1. - RIP))
MTBF/ (LRU oper hr/syst hr)(1 - ratio)

where MTBF = mean operating time between failures
UF = ratio of LRU operating hours to end-item operating hours, and
RIP = fraction of failures repaired-in-place

b. Total questionable corrective tasks generated monthly (TQCTGM) at each base (tasks/mo/base):

11. TQCTGM = PGMB * QTY/MTBCT
= (oper hr/mo/base) * (No. LRU)/(hr/failure)

where QTY = the number of LRUs in the end-item

c. Total life cycle repair demands (TLCD) at each base,

12. TLCD = TQCTGM * PIUP * 12.
(tasks/mo/base) * (yr/L.C.) * (mo/yr)

d. For LRU failure modes and matching SRUs, allocated life cycle demands.

13. TLCDF = TLCD * FAILP(i)
= L.C. demands/base * ratio of failures this failure mode.

e. Weighted depot repair cycle time (WDRCT)

14. WDRCT = DRCTO * OS + DRCTC * (1. - OS)
(mo. depot repair cycle time OS)(ratio) +
(mo. depot repair cycle time CON)(ratio)

where DRCTO and DRCTC are the depot repair cycle times, in months, for overseas and CONUS locations, respectively

f. Depot repair cycle time pipeline (DRCTPL) for all bases combined and the depot repair cycle time stock level (DRCTSL) evaluated on a per base basis.

15. DRCTPL = TQCTGM * WDRCT * M
(tasks/mo/base) * (mo repr cycle time)(No. bases)

16. DRCTSL = (DRCTPL + $\sqrt{3. * \text{DRCTPL}}$)/M
= A function of No. of items in depot pipeline

g. Base repair cycle time pipeline (BRCTPL) and stock level (BRCTSL)

17. BRCTPL = TQCTGM * BRCT
(tasks/mo/base) * (mo base repr cycle time)

where BRCT = the base repair cycle time in months

18. BRCTSL = BRCTPL + $\sqrt{3. * \text{BRCTPL}}$
= A function of No. items in base pipeline

h. Item requisition order and shipping time pipeline (OSTPL) and stock level (OSTSL)

19. OSTPL = TQCTGM * WOST
(tasks/mo/base)(mo weighted ship time)

20. OSTSL = OSTPL + $\sqrt{3. * \text{OSTPL}}$
= A function of No. of items in transit

The above quantities (a through h) are used in various equations. For the Poisson, the mean of the distribution, m, equals the variance, v, or m=v. For the Normal distribution with the standard deviation, s, s= $\sqrt{v}$. Then using, the Normal approximation to the Poisson at the 96% confidence level and a one tailed distribution, the stock level = $(m + 1.73\sqrt{m}) = (m + \sqrt{3m})$

The remainder of this section presents the cost equations used for each of the three repair level options for an LRU: depot repair, scrap, and base (i.e., intermediate) level repair. The cost equations will be identified as C1 through C9 to correspond to the nine item related logistics costs shown in Table 13. Further, each identifier (C1,...,C9) will have D, S, or B as a suffix to designate the depot, scrap, and base options, respectively. Thus, C1D is used for the life cycle replacements equation for the depot repair option, and C1S is used for the life cycle replacements equation for the scrap option.

The logistics cost equations are computed using the LRU cost and weight with the factors that are specified for each LRU failure mode. In reviewing the equations it must be remembered that each equation is evaluated for each failure mode of each LRU.

C1. Life Cycle Replacements.

For the scrap option the cost of purchasing a replacement for every failure is:

21. C1S = FAILP(i) * TLCD * UCL
(ratio) * (repr/L.C.) * ($/Item)

when FAILP(i) = the failure mode fraction (frequency of occurrence of the i^{th} failure mode as a fraction of all failures of the LRU)
UCL = unit cost of the LRU

For the repair options the cost of purchasing piece-parts and/or non-reparable assemblies consumed in the repair process is:

22. C1D = TLCDF * UCPPFM
(tasks/L.C.) * ($/fail)

where TLCDF = FAILP(i) * TLCD
(ratio) (tasks/L.C.)
UCPPFM = the total unit cost of repair parts and/or assemblies

23. C1B = C1D

C2. Life Cycle Packing and Shipping Cost.

For the scrap option the cost of shipping replacement LRUs from depot to base is:

24. C2S = TLCDF * WGTL * WPSR
(tasks/L.C.)(lb/package)($/lb pack & ship cost)

where WGTL = the weight of the LRU, in pounds

For the depot repair option the LRU must be shipped to the depot for repair and then back to the base:

25. C2D 2. * TLCDF * WGTL * WPSR
(directions/trip)(tasks/L.C.) * (lb/package) * ($/lb packing & ship cost)

If the LRU is base repaired then the necessary repair parts must be shipped from the depot to the base for each failure:

26. C2B = TLCDF * WTPPFM *WPSR
(tasks/L.C.)(lb parts/task) * ($/lb pack & ship cost)

where WTPPFM = the weight, in pounds, of repair parts and/or assemblies

C3. Base Stock Level.

For the scrap and depot repair options the base will maintain a stock of spare LRUs to satisfy demands which occur during a depot to base order and shipping time cycle. The quantity of spares required for the LRU is OSTSL. Therefore, the value of the assets, prorated to the i^{th} failure mode is:

27. C3S = FAILP(i) * OSTSL * UCL
(ratio) * (No. LRUs) * ($/LRU)

28. C3D = C3S

If the LRU is base repaired, then the base will have an inventory of spares to satisfy demands during the base repair cycle time. The value of these assets, by failure mode is:

FAILP(i) * BRCTSL * UCL
(ratio) * (No. LRU) * ($/LRU)

For each failure mode, there are certain piece-parts and/or nonreparable assemblies required for LRU repair. The expected annual cost for these parts at each base will be:

29. A = UCPPFM * FAILP(i) * TQCTGM * 12.
($/task) * (ratio) * (failures/mo/base) * (mo/yr)

The value of the base level inventory of these parts is based on an Economic Order Quantity (EOQ) formula (see AFM 67-1, VOL 2, Part2, Chapter 11). Let Q = economic order quantity in units, EOQ = economic order quantity in dollars, λ = annual demand in units, K = cost to order, C = unit cost, A = λC = annual demand in dollars, and I = holding cost as a portion of the unit cost. Using the classical EOQ formula, Q = $\sqrt{2\lambda K / IC}$, and EOQ = CQ = $\sqrt{2K / I}\,\sqrt{A}$. But K = $4.54 and I = .26 from AFM 67-1, Vol II, Part One, Amendment 20, 18 May 1981.

Then the current value of EOQ = $\sqrt{2(\$4.54)/.26}\,\sqrt{A} = 5.9\,\sqrt{A}$. Users should periodically review the reference and update the coefficient $\sqrt{2K/I}$, now 5.9.

30. EOQ = 5.9 * $\sqrt{A}$

This value is then checked and, if necessary, modified so that it reflects a cost no greater than the annual cost (A) and no less than the corresponding monthly cost (A/12.). Finally, the total base stock level cost is:

31. C3B = FAILP(i) * BRCTSL * UCL + EOQ
(ratio) * (No. LRU/base)*($/LRU) + (EOQ $)

<u>C4. Depot Stock Level.</u>

If repair for the LRU is done at depot level then the depot will stock spare LRUs to satisfy demands which occur during the depot repair cycle time. The cost of these assets prorated to the failure mode is:

32. C4D = FAILP(i) * DRCTSL * UCL
(ratio) * (No. LRU in depot) * ($/LRU)

If repair for the LRU is done at base level there is no requirement for spare LRU's at the depot. Therefore:

33. C4B = 0.

C5. Life Cycle Repair Labor Costs.

For depot repair:

34. C5D = TLCDF * DMMH * DLR
(tasks/L.C./base) * (hr/tasks) ($/hr)

where DMMH = the depot level maintenance man-hours required for repair, and
DLR = the depot labor wage rate

For base repair:

35. C5B = TLCDF * BMMH * BLR
(tasks/L.C./base)(hr/task)($/hr)

where BMMH = the base level maintenance man-hours required for repair, and
BLR = the base labor wage rate

C6. Air Force Inventory Item Introduction and Management Costs.

36. C6D = NPPA * RIIMC
(No. items) * ($/item/base)

where NPPA = the number of new piece parts and assemblies required for repair

37. C6B = C6D

C7. Base Level Item Management Costs.

A decision to do LRU repair at the depot implies that the base supply system will manage one new item, the LRU. However, since the same cost is incurred for the scrap and base repair options it is not computed for any repair level option. Thus:

38. C7D = 0.

Conversely, if the LRU is base repaired, then the base supply system must manage the LRU, all new piece-parts/assemblies required for LRU repair, and other piece-parts/assemblies required for LRU repair which are already in the AF inventory; but which will be new at the bases doing LRU repairs. Therefore:

39. C7B = PIUP * SA * (NPPA + NAB)
(yr/L.C.)($/item/yr) * (No. new parts + No. new parts at base)

where SA = the annual cost to manage one item in the base supply system,
NPPA = the number of new items, and
NAB = the number of items which will be new at base level

C8. Technical Data Costs.

The cost of acquiring technical data for performing LRU repairs is computed on a per base basis as:

40. C8D = NTDFM * TD/M
(No. pages) * ($/page)/(No. bases)

41. C8B = C8D

where NTDFM = the number of technical data pages required for repair of the LRU, and
TD = the cost per original page of tech data from the contractor

C9. Training of Maintenance Personnel.

For the depot repair option the expected number of repair man-hours required per month is computed as:

42. Hours = FAILP(i) * TQCTGM * DMMH * M
(ratio) * (tasks/mo/base) * (repr hr/task) * (No. bases)

This value is converted to the number of maintenance men required by:

43. MENREQ = Hours/DAA
(hr/mo)/(hr/mo/man)

where DAA = monthly available hours per man at the depot repair facility

Then, MENREQ is rounded to the next higher integer and compared to the user supplied value for the number of men to be trained. The larger value is used for MENREQ in the computation:

44. C9D = TFD * MENREQ * TRW * (TRC + 40. * DLR)/M
(ratio)*(No. men)*(wk/man)*($/week + hr/wk * $/hr)/(No. bases)

where TRW = the amount of time required for training expressed in weeks, and
TRC = the expected training cost per week for instruction and materials

The corresponding computations for base level training are:

45. Hours = FAILP(i) * TOCTGM * BMMH
(ratio) * (failures/mo/base) * (hrs/failure)

MENREQ = Hours/BAA
(hr/mo/base)/(hr/mo/man)

where BAA = monthly available hours per man at the base repair facility

46. C9B = TFB * MENREQ * TRW * (TRC + 40 * BLR)
(ratio * (No. men/base) * (wk/man)*($/week + hr/week * $/hr)

The above cost equations are summed for each failure mode to yield the total depot repair, scrap, and base repair costs:

47. DEPOT $ = C1D + C2D + C3D + C4D + C5D + C6D + C8D + C9D

48. SCRAP $ = C1S + C2S + C3S

49. BASE $ = C1B + C2B + C3B + C5B + C6B + C7B + C8B + C9B

2.2 <u>SRU Computations</u>. SRU cost equations are essentially identical to those for LRUs except that SRU factors are used in place of LRU factors. Two exceptions to this rule exist, the use of TLCDF and FAILP(i) * TQCTGM. TLCDF is the total life cycle demands for a particular LRU failure mode and, therefore, is also the total life cycle demands for the SRU associated with the LRU failure mode. Similarly, FAILP(i) * TQCTGM gives the expected number of monthly failures for a particular LRU failure mode and, thus, is also the expected number of SRU failures per month.

As in the previous section, the cost equations will be identified as C1 through C9 with the suffixes D, S, and B. In addition, since some SRU related costs are incurred dependent on the LRU decision the cost equations are assigned the suffixes D1 and D2. D1 and D2 correspond to DEC1 and DEC2, respectively, as shown in Table 13.

The logistics cost equations for SRUs are:

<u>C1. Life Cycle Replacements.</u>

For the SRU scrap option the cost of purchasing a replacement for every failure is computed as:

50. C1S = TLCDF * UCS
(tasks/L.C.) * ($/SRU)

where UCS = the unit cost of the SRU

For the repair options the cost of purchasing piece-parts and/or non-reparable assemblies consumed in the repair process is:

51. C1D = TLCDF * UCPPS
(tasks/L.C.) * ($ piece parts/task)

52. C1B = C1D

where UCPPS = the total cost of SRU repair parts

<u>C2. Life Cycle Packing and Shipping Cost.</u>

For the scrap option an SRU must be shipped from depot to base for each SRU failure <u>if</u> the LRU is repaired at the base. Therefore, the cost of shipping replacement SRUs is:

53\. C2D2 = TLCDF * WGTS * WPSR
(tasks/L.C.) * (lb/SRU) * ($/lb pack & ship)

where WGTS = the weight of the SRU in pounds

For the SRU depot repair option a cost is incurred <u>if</u> the LRU is base repaired. In this case, two way packing and shipping charges are incurred. The equation:

54\. C2D1 = TLCDF * WGTS * WPSR
(tasks/L.C.) * (lb/SRU) * ($/lb pack & ship)

represents one way transportation and is used with C2D2 to reflect the round trip total cost.

Base repair of the SRU only occurs if the LRU is also base repaired. In this case, piece-parts and/or non-reparable assemblies must be sent to the base for each SRU failure.

55\. C2B = TLCDF * WTPPS * WPSR
(tasks/L.C.) * (lb piece-parts/task) * ($/lb pack & ship)

C3. Base Stock Level.

For the SRU scrap option and the SRU depot repair option the base will have an inventory of spare SRUs <u>if</u> the LRU is base repaired. The spare assets are needed to satisfy SRU demands expected to occur during an order and shipping time cycle. The applicable SRU pipeline (SOSTPL) and SRU stock level (SOSTSL) quantities are:

56\. SOSTPL = FAILP(I) * TQCTGM * WOST
(ratio) * (tasks/mo/base) * (mo order & ship time)

57\. SOSTSL = SOSTPL + $\sqrt{2 * \text{SOSTPL}}$

= a function of SRU pipeline qty

The value of spare assets is:

58\. C3D2 = UCS * SOSTSL
($/SRU) * (No. SRU/base)

For the SRU base repair option, the base level inventory will contain spare SRUs and repair parts for SRUs. The spare SRUs are used to satisfy SRU demands (to support LRU repairs) during the SRU base repair cycle time and the SRU repair parts are used to satisfy repair parts demands. Using the EOQ formula mentioned in the previous section for the repair parts computation:

59\. A = UCPPS * FAILP(I) * TQCTGM * 12.
($/task) * (ratio) * (tasks/mo/base) * (mo/yr)

60\. EOQ = 5.0 * $\sqrt{A}$

where EOQ is changed, if necessary, to be no greater than the annual cost and no less than the corresponding monthly cost. The inventory cost for spare SRUs is obtained by first computing the expected SRU base repair cycle time pipeline quantity (SBRCTP) and the associated stock level (SBRCTL):

61. SBRCTP = FAILP(i) * TOCTGM * SBRCT
(ratio) * (tasks/mo/base) * (mo base repr cycle time)

where SBRCT = SRU base repair cycle time in months

62. SBRCTL = SBRCTP + $\sqrt{3. * SBRCTP}$
= a function of base repair cycle time

then

C3B = UCS * SBRCTL + EOQ
($/SRU) * (No. SRU/base) + ($/base)

C4. Depot Stock Level.

A depot inventory of spare SRUs is required to meet base demands for SRUs if the LRU is base repaired and the SRU is depot repaired. The value of depot spares to be prorated to each base is a function of the SRU weighted depot repair cycle time (SWDRCT), the expected pipeline quantity (SDRCTP), and the associated depot stock level (SDRCTL).

63. SWDRCT = SDRCTO * OS + SDRCTC * (1. - OS)
(mo depot repr cycle time OS)(ratio OS) +
(mo depot repr cycle time CON)(ratio CON)

where SDRCTO = SRU depot repair cycle time for overseas locations, and

SDRCTC = SRU depot repair cycle time for CONUS locations

64. SDRCTP = FAILP(i) * TOCTGM * SWDRCT * M
(ratio) * (tasks/mo/base) * (mo) * (No. bases)

65. SDRCTL = (SDRCTP + $\sqrt{3. * SDRCTP}$)/M

66. C4Di = UCS * SDRCTL
($/SRU) * (No. SRU/base)

C5. Life Cycle Repair Labor Costs.

For depot level repair:

67. C5D = TLCDF * DMMHS * DLR
(tasks/L.C./base) * (man-hr/task) * ($/maint man-hr)

where DMMHR = depot level maintenance man-hours required for SRU repair

For base level repair:

68. C5B = TLCDF * BMMHS * BLR
(tasks/L.C./base)(man-hr/task)($/maint man-hr)

where BMMHS = base level maintenance man-hours required for SRU repair

C6. Air Force Inventory Item Introduction and Management Costs.

As is the case for LRU repair, this cost is the same for depot repair and base repair.

69. C6D = NPPAS * RIIMC
(No. piece-parts) * ($/base/item/L.C. item mgt cost)

70. C6B = C6D

where NPPAS = the number of new piece-parts and assemblies required for SRU repair

C7. Base Level Item Management Cost.

For the base repair option, the base must manage all new repair parts for the SRU and all repair parts which are in the AF inventory, but which will be new to the repairing bases.

71. C7B = PIUP * SA * (NPPAS + NABS)
(yr L.C.) ($/item/yr) * (No. new items syst + No. new items base)

where NPPAS = the number of new items, and
NABS = the number of items that will be new at base level

C8. Technical Data Costs.

The cost of acquiring technical data for performing SRU repairs is computed on a per base basis as:

72. C8D = NTDS * TD [illegible]
(No. pages) * ($/page)/(No. bases)

73. C8B = C8D

where NTDS = the number of technical data pages required for repair [illegible]

C9. Training of Maintenance Personnel.

Training costs are computed for SRUs using the same method as for LRUs. For the depot option:

74. Hours = [illegible]
[illegible] * MH [illegible]) * (No. [illegible])

75. MENDEC = [illegible]

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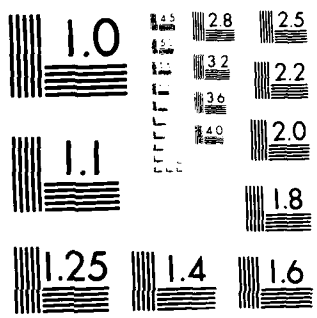

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76. C9D = TFD * MENREQ * TRWS * (TRCS + 40. * DLR)/M
(ratio) * (No. man) * (wk/man) * ($/wk + hrs/wk * $/hr)/
(No. bases)

where TRWS = the amount of time required for training, and
TRCS = the expected training cost per week

Hours = FAILP(i) * TQCTGM * BMMHS
(ratio) * (tasks/mo/base) * (hr/task)

77. MENREQ Hours/BAA
(hr/mo/base)/(hr/mo/man)

78. C9B = TFB * MENREQ * TRWS * (TRCS + 40. * BLR)
(ratio) * (No. men) * (wk/man * ($/wk + hr/wk * $/hr)

79. DEPOT $ = C1D + C5D + C6D + C8D + C9D

80. SCRAP $ = C1S

81. BASE $ = C1B + C2B + C3B + C5B + C6B + C7B + C8B + C9B

82. DEC1 $ = C2D1 + C4D1

83. DEC2 $ = C2D2 + C3D2

The sum labeled DEPOT $ is applicable _if_ the LRU containing the SRU is depot repaired; if the LRU is base repaired, then the applicable SRU cost is DEPOT $ + DEC1 $ + DEC2 $. Similarly, the SCRAP $ cost is applicable _if_ the LRU is depot repaired, but when the LRU is base repaired then the SRU cost is SCRAP $ + DEC2 $.

2.3 Support Equipment Computations.

Three types of support equipment costs are summed to reflect the SE investment at depot and base level: new facilities, SE acquisition, and life cycle SE operations and maintenance cost. The SE facilities cost (SEFAC) is not computed by the program; it is a user supplied value for each SE resource. The other two costs are determined as a function of the number of units of the SE required to support the repair workload.

The monthly workload for each SE is computed by summing, for every LRU and/or SRU which requires the SE, the product of the expected number of monthly failures times the maintenance man-hours required for each repair. For new SE resources the number of units required (REQMT) is the total usage hours per month (USEHRS) divided by the number of hours per month that the equipment will be available (OPHRS). That is,

84. REQMT = USEHRS/OPHRS
(reqd user hr)/(hr/mo avail on SE)

with REQMT adjusted to the next higher integer.

For SE resources which currently exist, at depot and/or base level, the REQMT is determined based on the existing available repair time (AVHRS):

85. AVHRS = NSE * (OPHRS - BSYHRS)
(No. SE) * (op hr/SE - busy hr/SE)

where NSE = the number of units currently installed, and

BSYHRS = the number of hours currently utilized on each unit

If AVHRS is greater than the new workload requirement, USEHRS, then REQMT will be zero; otherwise the REQMT is successively incremented by 1 until the additional available hours will satisfy the USEHRS required.

The SE acquisition cost (SEACQ) is:

86. SEACQ = REQMT * UCSE
(No. SE) * ($/SE)

where UCSE = the unit cost of the SE resource

The SE operations and maintenance cost is:

87. SEOPNS = (AINT (USEHRS/OPHRS) + 1) SEOPFF * PIUP
(reqd user hr)/(hr/mo avail on SE) ($/year) (yr L.C.)

where SEOPF = the annual cost of operations and maintenance of the SE

The total SE cost per life cycle is:

88. SECOST = SEFAC + SEACQ + SEOPNS
($ facilities + $ SE acquis + $ SE operations)

For depot SE resources this value is divided by the number of bases to obtain a per base cost. Similarly, for SE software to be used at depot level the total cost is divided by the number of bases in order to obtain a per base cost for software development.

The SE development is

89. SEDEV = DEV * 1000./M
($/base)

where DEV = the SE development cost in thousands of dollars.

NOTE, the SE development cost is divided by the number of bases to obtain a per base cost.

Appendix 4

Network Formulation and Solution

In order to understand the NRLA network formulation and solution a small non-NRLA example is given and application of the Max-Flow Min-Cut process is shown.

1. Max-Flow Min-Cut Applicability. The NRLA model employs a max-flow min-cut algorithm to determine repair level decisions which minimize expected costs. The applicability of this technique will be explained by an example.

Consider a situation in which a fluid is to be pumped through a pipeline from location S to location T. The locations are connected, via intermediate locations, by two pipelines, S-A-C-T and S-B-D-T as shown in Figure 21. The numbers next to each arc represent the fluid carrying capacity of the pipe connecting the locations. Thus, the maximum flow from location S to location A is 18 gallons per minute and from S to B the maximum is 9. Therefore, the total output capacity of S is 18 plus 9, or 27. Similarly, at T the maximum input capacity is 15 plus 13, or 28. However, the actual maximum flow from S to T is not 27 or 28. The flow along the route S-A-C-T is constrained to 15, the maximum capacity from C to T. Similarly, the maximum capacity from S to B limits the flow along the other pipeline to 9. Consequently, the total maximum flow from S to T is 15 plus 9, or 24.

The above discussion focused on finding the maximum flow through a network. This maximization approach may seem inappropriate for the repair level decision problem in which the objective is to find a minimum cost solution. The apparent inconsistency can be resolved by taking a different view of the network shown in Figure 21.

Suppose that the network still represents a pipeline through which a fluid flows but the problem to be solved is to determine the best way to stop the fluid flow. Assume that the flow in any of the sections of the pipeline can be stopped by purchasing a plug, and that the cost of a plug is directly proportional to the capacity of the pipe for which it is purchased. For example, a plug for the section from S to A would cost $18, and for the section from S to B, $9.

The total flow could be halted by plugging the two pipes emanating from S at a cost of $18 plus $9, or $27. Similarly, the flow could be halted at T by purchasing plugs costing $15 and $13, or $28. There are seven other combinations of two plugs which can be used to cut off the flow from S to T. The least cost combination involves the arcs S-B and C-T at a total cost of $24.

The fact that the numeric value of the minimum cut, 24, is identical to the value for the maximum flow is not coincidental. This occurs because each is directly a function of the constraining arcs in the network. That is, by finding the minimum cut for a network the maximum flow is also found.

To convert from the fluid flow network to an RLA cost network, consider a redefinition for the numbers on the arcs. Now the 18 and 9 represent the cost of performing depot repair for two different items. The 20 and 16 represent the costs for scrapping the items, while 15 and 13 represent base repair costs. The problem is now to find the least cost repair alternatives.

The cost for depot repair of both items would be 18 plus 9, or 27; scrapping both items would be 36; and base repair for both items would be 28. The least cost alternative is 15 plus 9, or 24. This decision represents base repair for one item and depot repair for

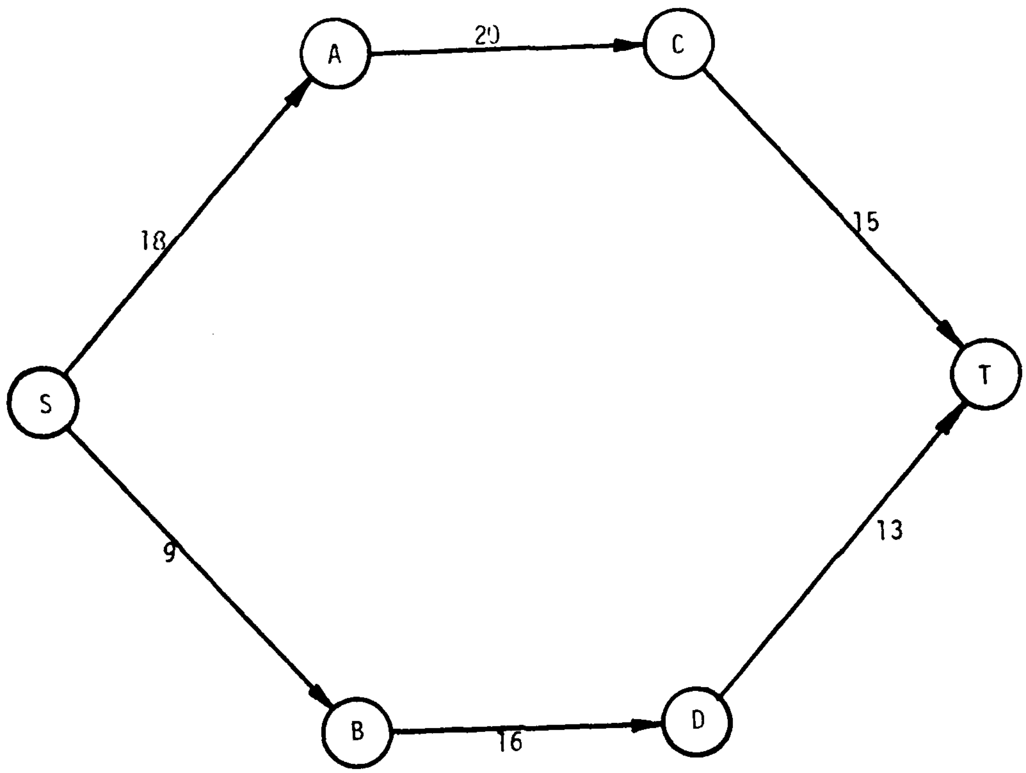

FIGURE 21. Sample Network.

the other. Note that the cost of these two decisions, 24, is the same as the result obtained in the fluid flow example when considering the *maximum flow* and the minimum cut. Thus, the repair level decision problem can be formulated in terms of a network and solved with a max-flow min-cut algorithm to determine the least cost decisions.

Although the above example does not include LRU to SRU relationships or support equipment requirements they are easily accommodated into the network structure. The method for including them is presented in the next section.

2.0 The NRLA Network

2.1 Network Construction. In order to fully understand the operation of NRLA it is necessary to understand how the ten types of decision cost factors can be structured as a network. Figure 22 a, b, and c shows such a network. Three variations are used in order that all information required may be easily visualized. They all represent the same network. The circles or nodes serve to act as markers defining the arc ends enabling easy identification. In terms of a pipeline they represent joints. The lines 1 through 7, and 2a represents cuts. These are discussed in section 2.3. In Appendix 3, Equations 47-49, 79-83, and 88 are used to represent ten kinds of costs. (Equation 88 represents SE at depot and at base when different variable data is used.) These equations were shown in a tabularized form in Table 13 in Appendix 1. We see how the eleven logistic factors were summed to ten decision cost factors representing the ten decision components. Figure 22 represents the ten cost factors as a network.

2.2 Relational Arcs

The normal sized arcs represent potential decisions. The heavy arcs represent "dummy" or relational arcs. They are used to permit flows but they can never restrain flows. If the network is viewed as a pipeline, arcs 1-2, 1-3, 4-6, 5-4, and 5-6 would have very large diameters, each perhaps with a diameter as large as the sum of all other (non-dummy) arcs. In terms of costs the very large costs associated with large diameters are pseudo-costs. The large pseudo-costs prevent the dummy arcs from ever limiting or restricting the flow. We always choose to avoid them. The amount of flow in 1-2 and 1-3 is controlled by the flow in S-1. The flow in 1-2 or 1-3 can never limit the flow in S-1. Notice that there are ten non-dummy arcs. These represent the ten possible decision factors discussed in Appendix 1, Table 13.

The ten decision cost factors when structured as a network with the proper set of relational arcs permits the seven decisions in Table 14 and the seven cuts of Figure 22.

2.3 Cuts

Before explaining the dummy or relational arcs it is first necessary to define a cut. We should consider that when a set of decisions is selected, mathematically the nodes of the network have been divided into two sets, those associated with the S or source and those associated with the T or terminal. This is a cut. In Figure 22 we note that each of the cuts individually considered divides the network into two sets of nodes each associated with an S or T.

In "max-flow min-cut" problems we wish to find the least cost means of stopping the flow. Once a cut has been selected all the arcs leaving the S set or entering the T set and only these are the ones which "plug" the network. These are the cut set. The reader should consult a good book on network theory for greater detail on networks and cuts.

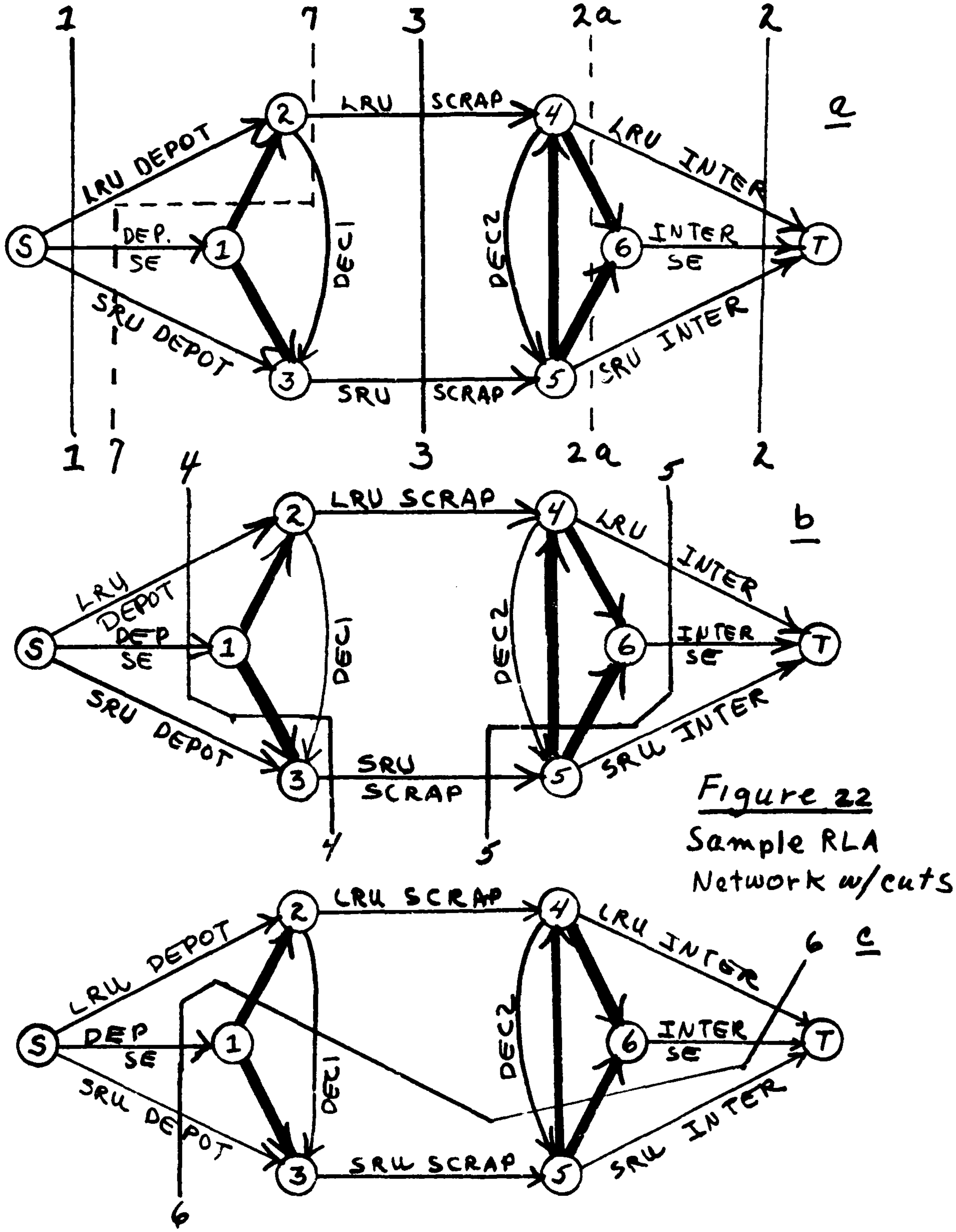

Figure 22
Sample RLA
Network w/cuts

Referring back to the figure we notice that none of the dummy or relational arcs act as plugs. They all enter the S set or leave the T set. The network was deliberately constructed in this fashion. The purpose of them is to prevent certain decisions. As an example: if cut 2a is used then LRU and SRU are both Base repaired but no SE is included. However the relational arcs 4-6 and 5-6 are so large (costly) that any solution excluding them and other dummies, will be less expensive.

Thus, 2a is a viable cut in that it would separate the network into an S and T set, but since the dummies 4-6 and 5-6 must be counted in the cost of the decision, it is a very expensive decision and cut 2 will always be a better selection. Thus, the dummies 4-6 and 5-6 force the use of SE at Base if either LRU or SRU is Base repaired. Arcs 1-2 and 1-3 act analogously to 4-6 and 5-6 except at the depot level. Arc 5-4 serves to prevent depot repair of the LRU combined with Base repair of the SRU.

2.4 Decision Arcs

The arcs 2-3 and 4-5 (DEC1 and DEC2) are used in order that certain inventory costs may be included with certain decisions. If the LRU is Base repaired and the SRU is scrapped, replacement SRUs must be transported from depot to base and stocked at base. These are DEC2 costs. If the LRU is base repaired and the SRU is depot repaired, SRUs must be stocked at both depot and base and transported both ways. Since DEC2 already carries Base Stock and one way transportation costs, DEC1 carries the depot stock costs and one way transportation costs. Combined as in Cut 6 they represent round trip transportation and stockage at base and depot.

2.5 Scrap Costs

Table 1 shows how the logistic costs are summed as necessary to obtain the ten arc costs. Equation numbers from Appendix 3 are then used to relate specific equations with the table. This is correct for all items except LRU scrap costs. For LRU scrap costs the required arc cost is the difference between the LRU cost and the SRU cost for the related failure mode. This is the difference between equation 48 and 50. This difference is used since cut 3 which is the cost of scrapping the LRU involves 2-4 the LRU scrap cost and 3-5 the SRU scrap cost. If summed as described then the SRU cost would have been included twice, once as part of the LRU in arc 2-4 and once as the SRU arc 3-5. By subtracting out the cost of the SRU from the LRU arc 2-4, cut 3 which requires the sum of 2-4 and 3-5 totals to the cost of the LRU when scrapped.

2.6 Solving the Sample Network

Returning to the non-dummy arcs the costs associated with the ten respective decision components are used to represent the diameters of the respective arcs. If the cost of stopping the flow in an arc (purchasing a plug) is proportional to its diameter, the question is, what is the minimum cost means of stopping the flow in the network? For which arcs should we buy plugs? It is precisely this problem that the mathematical algorithm called "max-flow min-cut" solves. This total then is the system cost of the decision. As an example in Figure 22, Cut 6 selects LRU at intermediate, Intermediate SE, DEC2, DEC1, SRU at depot and Depot SE for the failure mode represented. These costs then would be totaled to get the system costs.

If S-2, 2-4, and 4-T represent Depot, Scrap, and Intermediate repair for an LRU respectively, S-3, 3-5, 5-T represent the same for an SRU, and 2-3, 4-5 represent certain inventory carrying costs. There are seven possible valid decisions. These are shown in Table 14 and Figure 22.

As an example, Cut 4 shows LRU at depot, SE at depot, and SRU scrap being selected. Arc 2-3 (DEC1) is not cut. It enters the source group of nodes. The total cost for the life cycle is determined by summing the three elements (a) LRU at Depot, (b) Depot SE, and (c) Scrapping the SRU. Table 14 shows the same decision in a tabularized form.

By careful review of Tables 13 and 14 and Figure 22 the user will see how the eleven logistic factors developed in Appendix 1 may be summed to ten decision components. These ten decision components may then be structured as a network if the dummy arcs are used. The network permits only 7 feasible decisions. The selection of a particular decision depends upon the costs associated with the arcs of the network. The total cost is the sum of the cost of the cut arcs.

Cut 7 represents an anomolous situation. The LRU is scrapped, but the SRU is depot repaired. It is not possible to structure the network to exclude the possibility of Cut 7. If this result occurs, as previously noted, the user should rerun the network twice for each occurrence using the forcing procedure. The runs are (1) excluding LRU scrap and (2) forcing the LRU and SRU to be scrapped. The minimum of these costs represents the optimal solution.

2.7 Full Size Networks

Where more than one LRU or SRU is involved, additional arcs in parallel to those shown are required. Figure 23 shows a network with two LRUs, two SRUs, and two types of SE at Depot only, and one type at base.

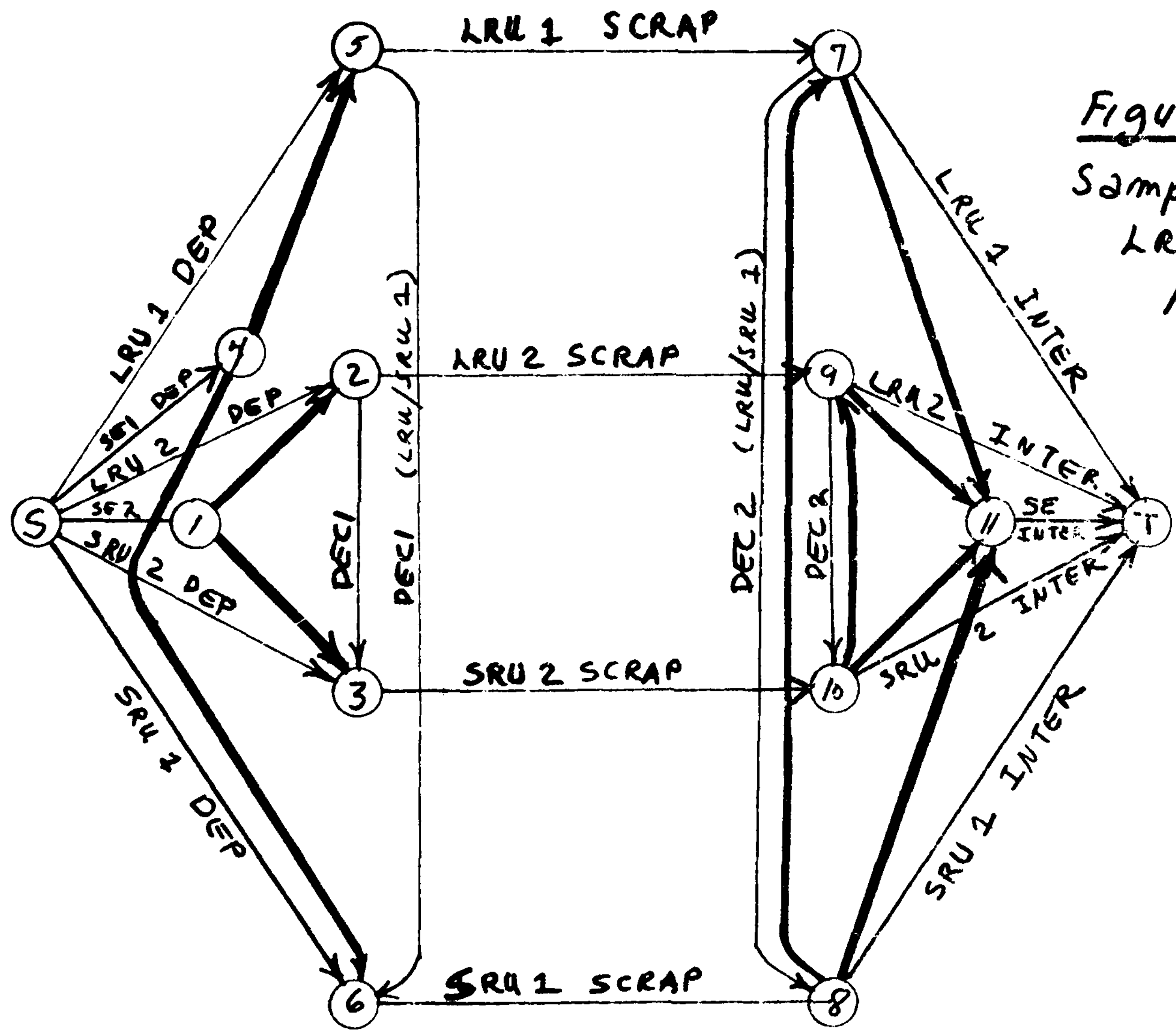

Figure 23
Sample Multiple LRU/SRU/SE Network

ED

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